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Historical Channel Adjustments in the Pascagoula River Basin and Adjacent Systems, Southeast Mississippi

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HISTORICAL CHANNEL ADJUSTMENTS IN THE PASCAGOULA RIVER BASIN AND ADJACENT SYSTEMS, SOUTHEAST MISSISSIPPI

by

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ABSTRACT

HISTORICAL CHANNEL ADJUSTMENTS IN THE PASCAGOULA RIVER BASIN AND ADJACENT SYSTEMS, SOUTHEASTERN MISSISSIPPI

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This project identifies historical cross-section adjustments in 13 rivers of the Pascagoula Basin and adjacent fluvial systems over the last 30-50 years, which could reveal hydrologic and sedimentary responses to natural causes such as flooding or various anthropogenic activities in the region, such as logging, urban development, and instream aggregate extraction. Historical depth and streamflow measurement notes, taken at established USGS gaging stations, were used to determine incremental width, depth, and discharge values. For each section and date, individual depth measurements were subtracted from the adjusted mean gage height, which represents the channel bed or submerged bank positions. Comparisons of cross-sectional plots at consistent locations through time enabled assessment of changes in shape, bed elevation, and spatial position. Despite proving useful for interpreting change at each specific location cross-sections generated from USGS gaging station reports, were not able to be extrapolated to characterize the entire channel reach or basin. Assertions in this thesis are only interpretations based on a limited understanding of watershed dynamics. Therefore, it is impossible to definitively associate channel adjustments with anthropogenic disturbances without other data to corroborate these findings.

ACKNOWLEDGMENTS

I would like to thank Mike Runner, P.E and Hydrologist, at the U.S. Geological Survey Mississippi Water Science Center in Jackson, Mississippi for helping me acquire the data for this project. I would also like to acknowledge the Gulf Coast Association of Geological Societies (GCAGS) for a 2011 Faculty Research Grant to Dr. Franklin T. Heitmuller that helped fund the trip to Jackson. I would like to thank my committee members Dr. Franklin Heitmuller, Dr. Omar Harvey, and Dr. Maurice Meylan for their assistance throughout the project and for their attentiveness during the defense. Lastly, I would like to thank in some way every individual over the past two and a half years who was involved with the geology program at The University of Southern Mississippi. This process definitely would not have been the same without you all.

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CHAPTER I

INTRODUCTION

Each of the Earth's heavily populated continents is bisected by innumerable rivers, life threads between civilizations, all ranging in lengths, widths, and depths. The behavior of these alluvial channels has been studied at great length with various approaches and technological improvements. The discipline of fluvial geomorphology considers channel adjustment in three geometric dimensions: (1) channel slope, (2) channel plan form, and (3) cross-sectional morphology. Whereas antecedent channel form is dependent on geologic structure and bedrock response to incision, controls over changes to the channel form are tied to hydrologic processes (e.g., discharge, turbulence) and sediment load (Dade and Friend, 1998). These controls are influenced across millions of years by environmental factors. General climate is manifested in seasonal precipitation trends or magnitude-frequency relations of floods and droughts. Within the scope of several years to decades, anthropogenic controls, including land cover change, reservoir impoundment, and direct channel modification, distress natural hydrologic processes and sediment distribution, resulting in rapid channel adjustment.

Importance

As humans continue to populate and develop areas proximal to rivers, rapid channel adjustment commonly results in increasingly negative effects. Such effects are both societal— including widespread damages to bridges, homes, businesses, and other structures as well as loss or frequent inundation of agricultural areas— and environmental— including damage to aquatic and riparian ecosystems and loss of alluvial groundwater storage and river-water table relationships (Rinaldi, 2003).

Understanding the morphological response of alluvial channels to a myriad of different controls has been recognized as paramount by the scientific community. This thesis gleaned its principles and examples from just a selection of the extensive number of studies documented cross-continent on river systems in Italy (e.g., Rinaldi, 2003), France (e.g., Poudevigne and others, 2002), and China (e.g., Xu, 2002); studies in the contiguous U.S.A have often been located from the Pacific Northwest through Texas (Heitmuller and Greene, 2009), and across the Midwest.

Purpose and Scope

The purpose of this thesis is to create a visual representation of historical channel cross-section adjustment in the Pascagoula River basin and adjacent coastal-draining rivers in southeastern Mississippi. This area is of interest for its location in a humid subtropical climate (Köppen Classification System) with particularly gentle topography superimposed on basin fill-sediments. The combination of climate and geographical setting differentiates this thesis from much of the previous literature on morphological adjustment.

Reconciling historical USGS data digitized from hard-copy stream flow measurement notes with characteristics of the channel reach, artificial hydraulic behavior at bridges, and possible changes to the arbitrary stage datum, quantifies cross-sectional channel adjustments at 19 gaging stations along 13 rivers in the study area. Site specific cross-sections along the main stem rivers and tributaries of the Pascagoula fluvial system could be integrated to provide a record of historical channel adjustments for the region. Documented changes in channel geometry over the last several decades can then be attributed to either naturally occurring fluvial processes (e.g., floods) or anthropogenic disturbances (e.g., logging-induced sedimentation, channelization).

The following research questions were addressed:

1. Is cross-section re-construction based on discharge measurements at USGS streamflow-gaging stations an appropriate method to analyze historical channel adjustment in southeastern Mississippi?

2. How have river cross-sections in the study area adjusted during the timeframe available from USGS records?

3. What are the possible controls of the cross-sectional adjustments given the natural characteristics (e.g., climate, geology) of the study area?

Study Area

The study area of interest is the Pascagoula River basin (Figure 1) in southeastern Mississippi and other nearby coastal-draining systems (e.g., Biloxi, Wolf Rivers). The Pascagoula River and its tributaries drain an area of 9,510 mi^2 into the Gulf of Mexico via the Mississippi Sound. The numerous rivers dissecting the basin are of varying size, providing a myriad of possible channel geometries for comparison. The river valleys occur in thick, basin fill deposits of alternating sandstones, mudstones, limestones, marls, and unconsolidated sediments of Tertiary and Quaternary-aged transitional marine and alluvial sediment. The Hattiesburg Formation, identified by blue-green clay, gray siltstone, and sands, was deposited over mainland Mississippi in a sublittoral embayment, the result of the Tortonian transgression and other marine cycles during the Miocene (Otvos, 1994). The Hattiesburg is overlain by the distinctive red sands and gravels of the

Citronelle formation. This unconsolidated, siliciclastic alluvium is the most widespread formation along the Gulf of Mexico's northeastern coastal plain (Otvos, 1998).

Structurally, the subsurface slopes gently, at an almost imperceptible six ft/mi (Carsey, 1950). An exception to this is found along an east-west transect across Bogue Homo and Tallahala Creek, where neotectonic uplift has been documented. Upstream from the axis of uplift these rivers record weakened flow and less erosion from a decrease in slope (Burnett and Schumm, 1983).

Climate for the study region is designated by the Köppen Classification System as a mild "mid-latitude climate with no dry season and a hot summer" (referred to as Cfa) (Peele and others, 2007, p. 447).

Extensive conservation efforts have been maintained to preserve the Pascagoula River basin's status as the largest virtually unregulated river system in the conterminous United States. The absence of artificial impoundments along main-stem rivers and major tributaries offers an ideal opportunity to limit the possible effects of other anthropogenic disturbances on channel adjustments.

The Biloxi and Wolf Rivers are additional fluvial systems included in this study that exist outside of the Pascagoula River basin. These systems are regulated by the same topography, surface geology, and lack of hydrologic regulation, thus complementing the Pascagoula River dataset.

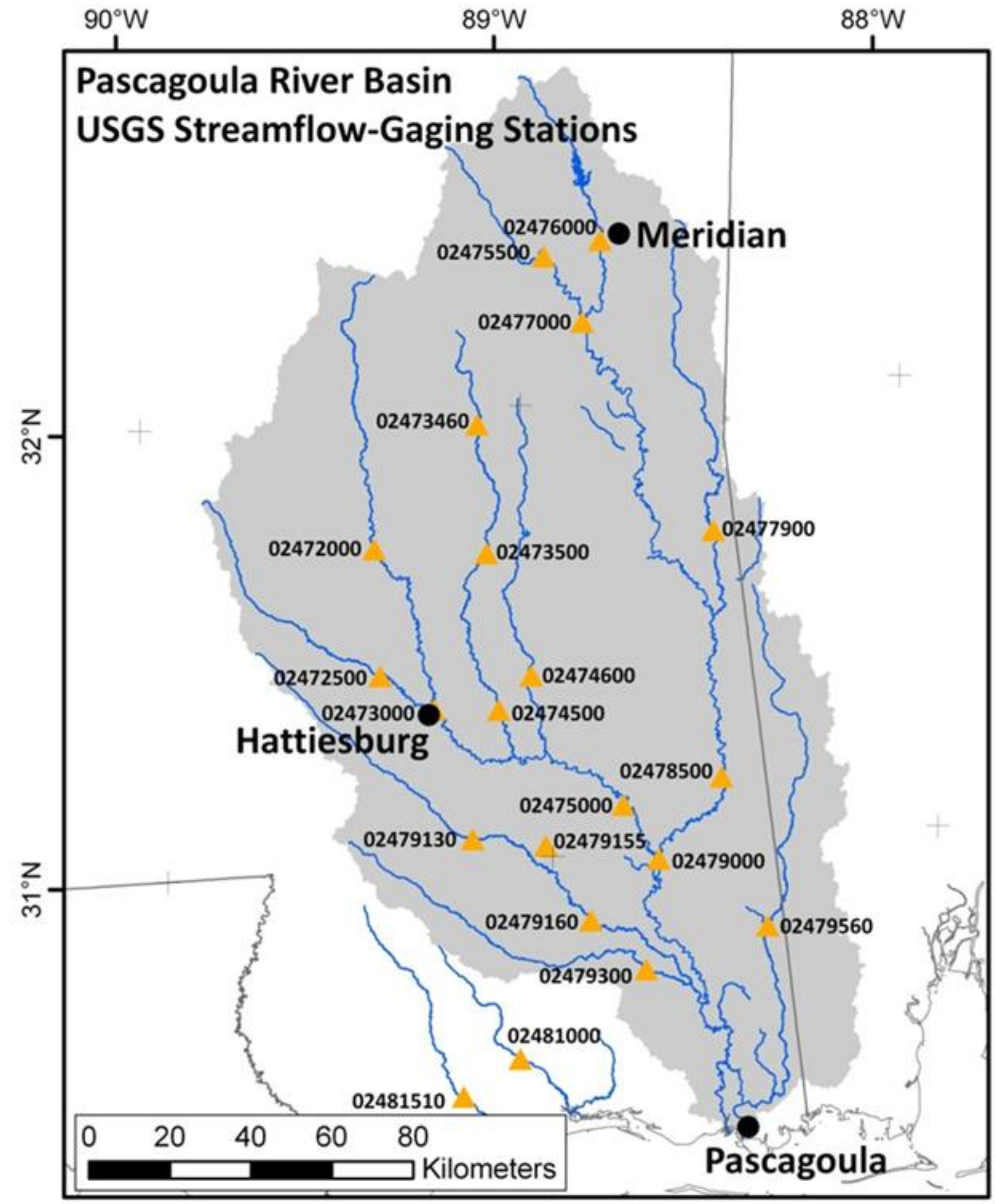


Figure 1. Map of the rivers and tributaries that comprise the Pascagoula River basin, southeastern Mississippi. U.S. Geological Survey streamflow gaging stations are identified by USGS site codes (Heitmuller, GCAGS 2012).

CHAPTER II

LITERATURE REVIEW

Mechanisms of Channel Change

Channel adjustment occurs in three dimensions: slope, planform, and cross-sectional geometry. Morphological changes of alluvial rivers in the Pascagoula basin will manifest differently than channels formed in competent bedrock. Alluvial rivers will comparatively tend to have minimal slope, which can fluctuate from incision or aggradation. From a plan form perspective these rivers are susceptible to changes in sinuosity, either increasing and eventually leading to neck cutoffs or decreasing to a relatively straight course. Bedrock controlled channel forms are dictated by rates of incision, dependent on the different consistencies and geometries (dip angles, bedding orientation) of in-channel outcrops (Toone and others 2014). Alluvial channels adjust in a less constrained way to hydraulic and sedimentary controls, garnering the distinction "authors of their own geometries" (Leopold and Langbein, 1962, p. 1).

Rivers are the primary agents of downstream transport for water and sediment from the catchment area. Water discharge can broadly be referred to as a product of climate and sediment discharge, a product of tectonic setting. These two factors are not independent of one another, as semi-arid regions supply greater amounts of sediment to rivers relative to humid regions (Langbein and Schumm, 1958), but work as representing general categories (Daniels, 2008). Consequently, changes in the form of a given river channel (i.e., slope, plan form, and/or cross-sectional geometry) are driven by a deviation from an established stream-specific equilibrium between water discharge rate and sediment load. For example, disequilibrium favoring a higher than normal-sediment load and lower-than-normal, water discharge rate would trigger aggradation of particles, resulting in a rise in channel-bed elevation. Conversely, disequilibrium favoring a lower-than-normal sediment load and higher-than-normal water discharge rate would trigger incision of the substrate, resulting in a lowering of the channel-bed elevation.

It is also not uncommon for channel-bed aggradation and degradation to produce further alteration to cross-sectional channel form through channel widening, bar development, and narrowing. Fluid scour in non-cohesive coarse banks, as well as lateral spread (arising from insufficient deepening to accommodate higher-than-normal water discharge rates) can result in channel widening (Sarmah, 2012). A sudden drop in stream base level, due to channel-bed degradation, can result in incision induced channel widening as the channel cuts deeper, rendering the associated flood plains become unstable and prone to erosion and widening of the overall channel (Reading, 1996).

The sediment and water discharge components that drive changes in channel morphology are known to occur over varying time periods (Daniels, 2008). For example, fluctuations in tectonic activities impacting allogenic changes in sediment type, availability, and subsidence rate occur over geologic time periods (10^6–10^8 yrs). Precipitation averages and vegetation that control sediment yield through runoff are measurable over a value of Quaternary and Holocene time (10^2–10^5). Sea level change, which alters the base level of fluvial systems, also occurs within this time frame. Channel morphologies altered by pulse-style disturbances, such as large floods or storm events, are Observational in scale (10^{-3}–10^0).

Disequilibrium in water discharge rate and subsequent channel changes have also been linked to changes in climate, land use land-change, and other human activity (e.g., agriculture and dams) in the Observational time scale (10^{-2}–10^{1} yrs.). They have drawn a sizeable amount of research over recent decades. Gregory (2006) synthesized a review of human impact on fluvial systems from previously published studies in an effort to describe the scope of engineering projects. These are elaborated upon below.

Impoundment

Dams are ubiquitous features of many river systems across the world (Komura and Simons, 1967; McCully, 1996; Gopal, 2000; Schofield and others, 2000). Dams have been shown to reduce downstream sediment load, inducing incision and channel narrowing via scour and entrenchment. The inconsistent release of water downstream alters flood stage intervals and decreases floodplain stability, creating the potential for more frequent neck cutoff. In situ hazards are also increased; the area immediately under the dam is susceptible to destabilization through scour. Slopes and morphologies of tributaries associated with the main stem river are also affected, as their base level is altered by the impoundment of water (Brookes and Gregory, 1988). Similarly Surian and Rinaldi (2003) referenced numerous studies that evaluated reservoir construction. From the United States' Midwest regions across Colorado and into California, a consistent pattern of incision and channel narrowing was discovered downstream from dams. These conditions ranged from minor to extreme in each study with incised rates of 1–7 meters and channel narrowing at 10%–80% (Williams, 1978; Williams and Wolman, 1984; Andrews, 1986; Kondolf, 1995).

Channelization

Channelization, where a reach of stream is moved, straightened, diverted, or filled in greatly altering discharge and therefore channel form (EPA, 2005), has also been widely documented (Brookes and Shields, 1996). Known results of channelization range from incision to bank erosion, knickpoint development, and increased channel width followed by aggradation. Changes from channelization to hydrologic and sediment discharges have forced streams with braided patterns into a single thread (Brookes and Gregory, 1988). Again, Surian and Rinaldi (2003) catalogued specific examples of channelization in France, the United States and Scotland all with similar results (Lewin and Weir, 1977; Schumm and others, 1984; McEwen, 1989; Marston and others, 1995). Across these general areas, depth of incision was comparable (1–5m) to the effects from reservoir construction. Incision in braided streams is more likely to induce extreme channel narrowing. Heitmuller (2014) has indicated that meandering streams will only display significant bed elevation lowering. In the compilation of studies from Gregory (2006) deleterious effects to channel form were more common in cases of reservoir construction (present in 73% of studies) than in channelization (52%). Also included under the mantle of channelization are materials extraction, large woody debris (LWD) jams and removal, and dam removal.

Land Use/Land Cover

Land use and land cover are other anthropogenic forces that manifest in different ways with many of the same effects. Numerous studies (Knox, 2002) have highlighted land clearance practices such as deforestation thorough logging and burning and agricultural techniques of grazing and ploughing as promoting aggradation and bed elevation increase. Land clearance removes the protective vegetative cover over soils and results in increased erosion and sediment yield in runoff. This is especially true in areas with high gradients that are prone to large-scale hillslope erosion (Daniels, 2008).

Urbanization is quite different in that it promotes incision through an increase in peak discharges and a concomitant decrease in sediment transport. Rapid runoff over paved surfaces introduces hungry water into the fluvial system, while storm drainage systems expand the drainage basin (Gregory, 2006).

Water Diversion

In cases where water abstraction or river diversions are implemented aggradation is observed in the immediate area as stream power is decreased. Where that water is returned further downstream through culverts or drainage scour is likely. Karr and others (2000) indicated that 11% of freshwater runoff in North America is abstracted for use.

Mechanisms Common to Study Area

The unregulated nature of rivers (Dynessius and Nielsen, 1994), an absence of urban centers, and a lack of widespread agricultural activity within the Pascagoula River basin means that many of the anthropogenic factors described above are absent from the basin and, therefore, play no significant role in channel readjustment within the study area. However, this did not preclude anthropogenic impacts on channel changes. For example, in-channel and floodplain mining of sand and gravel aggregate, resulting pit avulsions, logging, and bridge construction or maintenance activities are some possible anthropogenic drivers for channel readjustment within the study area.

According to Mossa and Coley's (2004) interpretation of USGS land cover/use data, 68% of the Pascagoula River basin is classified as forested and only 3% of the basin is developed. The high acreage of forest would suggest the presence of LWD in the waterways. Further evidence to support a role for LWD is the study area's history of logging. At the onset of the 20th century Mississippi was ranked third nationally in timber production (Hickman, 1962). Timber remains a large source of revenue in the study area despite a decline in production over the course of the study period.

The presence of log jams, which occur when downstream movement of one log stops, persists, then collects other smaller racked members, has been documented (Wallerstein and Thorne, 1996; Webb and Erskine, 2003) to have more severe impacts on channel form in steeper channels where logs have high residence times. In low gradient channels, LWD move through the fluvial system more efficiently, but could still have important effects. Stable log jams may affect both the depositional and erosional capabilities of a stream. Surface elevations upstream from the LWD could rise as a response to obstruction and induce deposition. The object could also disturb flow, trapping sediment around it. The presence of LWD alters erosion rates by changing flow distribution patterns (Curran, 2010). Obstructions can divert flow towards channel banks, causing widening through scour, or become a barrier, thus blocking flow to the bank and decrease bank erosion. In Curran (2010), the San Antonio River demonstrates that although low-gradient streams have low LWD residence times, jams are more likely to reform. Through positive feedback response, a log that increases deposition will develop a channel bar that collects more wood and gathers more sediment, further stabilizing the bar. LWD most often accumulate in mid-channel bars or outside meanders. For this reason jams occur heavily in rivers with high sinuosity. Repeated jam areas will have channel form effects as extensive as long residency areas. It is important to note that in cross-sectional view morphology changes caused by LWD will appear similar to those caused by bridge construction. Cross-referencing the National Bridge Inventory Database

(NBID) (Nationalbridges.com, 2013) for construction dates will aid in differentiating between the two events.

The decline in timber production was met with the advancement of another channel bed modification process, in-stream and floodplain sand and gravel mining. Sand and gravel aggregate extraction is used for the construction of buildings and roads. Once coarser sediment is removed from the channel bed; incision occurs proximal to the extraction site. This is in response to the change in bed load composition becoming primarily mobile sands and fines. Scour and washout are also prevalent after the removal of flow impeding gravel bars (Rasmussen and Mossa, 2011). The eroded bed material has a tendency to redistribute far downstream, resulting in increased bed elevation. Higher frequency and magnitude overbank flow events add hazard to these aggradation sites. It could take decades for consistently captured bed load to fill the in-stream pit (Mossa and Marks, 2011; Grimball and Heitmuller, 2012). Mining in the floodplain leaves pit depressions that capture stream flow, resulting in a pit avulsion. Destabilization of banks also causes channel widening or repositioning as the point bar increases in area. Hydraulic flow properties are also altered by the change in bed composition. Preferential extraction of coarser material changes particle size number and distribution along the bed, altering roughness and flow rate (Mossa and Marks, 2011). Surian and Rinaldi (2003) and Ziliani and Surian (2012) established a morphological response for a cross-section under mining conditions. Initial incision of 3–4 meters, occasionally up to 7 meters, corresponding with channel narrowing was the observed trend. According to Simon (1989), rivers can experience a recovery cycle after incision. In Tennessee fluvial systems after 10 years of incision, a reversal toward aggradation commenced. The duration of recovery was itself 10–12 years and exhibited corresponding channel widening.

A similar trend toward incision after aggregate mining was measured in Rasmussen and Mossa (2011) on the Leaf River downstream of the Bouie River confluence. That reach of the Leaf River had about 1 meter of incision, while also becoming wider and shallower at the new elevation. Grimball and Heitmuller (2012) analyzed the flooded pits along the Bouie River in Hattiesburg, concluding that considerable sands from the Bouie River are becoming trapped in the flooded pits.

Methods for Assessing Historical Channel Adjustments

Past studies that assess planform features to quantify patterns of change often rely on aerial images or historic maps. Aerial photos or maps enable large portions of the river, meander migration, avulsion events, and widening through bank erosion to easily be documented. These remote data are paired with site surveys of differences in elevation or shape in common morphological features (e.g., channel bars, floodplain sediments, terrace position, the occurrence of sediment lobes or bed armoring) to increase accuracy (Ziliani and Surian, 2012). Successful implementation of reconciled remote data and site surveys is demonstrated by Toone and others (2014) and Ziliani and Surian (2012). Long-term channel widening and areas of vulnerability are found along the Tagliamento River in Italy and the Drome River in France, respectively.

Data acquisition and analysis techniques evolve with changing technologies. Sarmah (2012) used satellite imagery of the Jia Dhansiri River in India to confirm select dumpy level readings of channel width and bed elevation. The digitized images allowed extrapolation into broader cross sectional profiles to estimate the rate of bed aggradation.

Curran (2010) augmented maps with precise GIS coordination to track the mobility of in-channel LWD and its alteration of channel width. Models were developed from these data to project the hydrologic conditions behind LWD jams and morphological effects. Riahi-Madvar and others (2011), through an automatic neural network, modeled cross-sectional changes in alluvial systems from a range of parameters using widely available data. With discharge and sediment grain size as variables the model is able to predict width, depth, and slope of different channel regimes.

Changes in channel morphology are argued by Gregory (2006) and Ziliani and Surian (2012) to be more evident in cross-section. Channel geometry is greatly impacted by frequent pulse events of often unpredictable discharge that cause short-term channel changes observable in cross-section profiles that planform views would not detect.

Cross-sectional profiles can be used to track the response to changes in different variables throughout the watershed. In Xiu (2002), cross-sectional areas of the Yellow River were examined to demonstrate that in an unstable channel deposition rate has a major impact on morphological adjustment. Rasmussen and Mossa (2011) valued cross-section as a function of mean depth and width. They conducted a comparison of morphology across time, but instead of using old flow records they determined cross-sectional parameters of oxbow scars (abandoned former meanders) against parts of the contemporary channel. That study recorded a dramatically increased width to depth ratio.

The base method for this paper follows Heitmuller and Greene (2009) and Heitmuller (2014). In that study, channel bed elevations and cross-sectional distances were extrapolated from historical flow records collected at streamflow-gaging stations along the Brazos and Sabine Rivers in Texas. They were plotted to form cross-sectional profiles that provided visual cues of morphological adjustments over historical time frames (1920s–2000s). The cross-sectional profiles were proven to demonstrate a definitive look at aggradation/incision trends as well as bank erosion/narrowing trends.

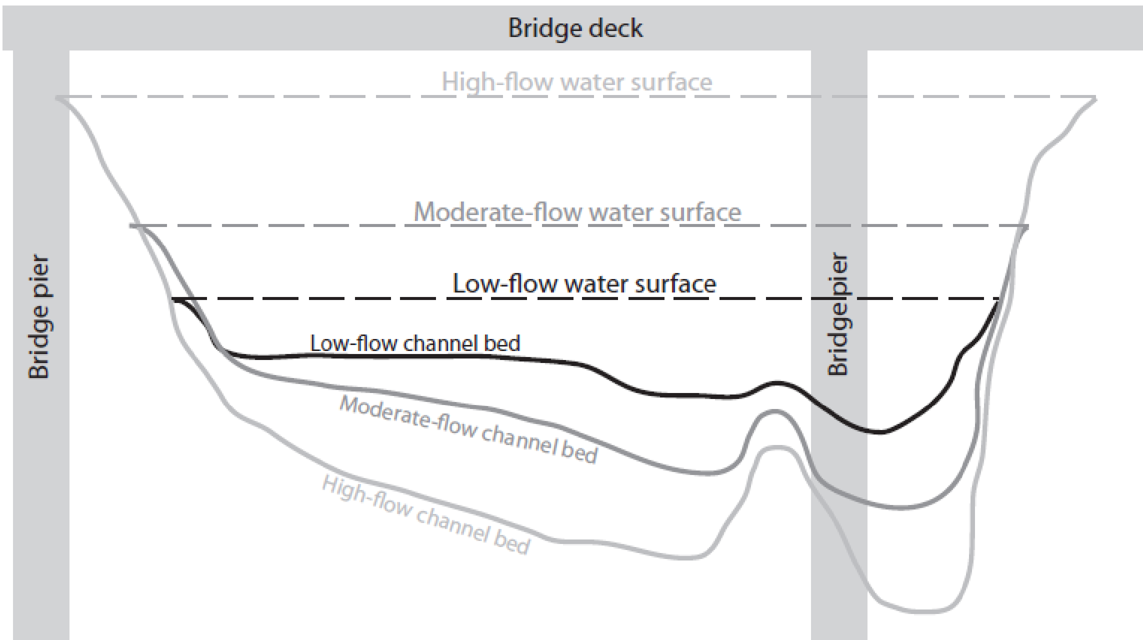


Figure 2. Conceptual diagram of channel bed forms observed at bridge gaging stations. Different forms are connected to varying flow stages. Scour and fill is a common occurence along alluvial channels (Heitmuller and Greene, 2009).

In addition to the base method, the study area for this paper is represented in previous research by Mossa and Coley (2004). That study included many of the same rivers, over the same duration, in the Pascagoula River basin (e.g., Chickasawhay, Leaf, Bowie, and Pascagoula Rivers) that are examined here. Rivers were rated for instability based on historical planform changes. When channel profiles were overlain the change in movement area was calculated. For example, increased sinuosity would qualify a river for unstable designation. Part of the discussion in this paper will examine if an unstable planform correlates to an unstable cross-sectional profile.

Methodology Justification for this Thesis

The use of USGS stream flow data to construct and interpret changes to channel cross-section morphology across several decades was demonstrated in Heitmuller (2014). In that study the lower Brazos and Sabine Rivers are similar to the streams in southeastern Mississippi when physiography (i.e., Gulf Coastal Plain), alluvial material, and slope (0.00015-0.0006) are considered. The streams chosen from the Pascagoula River Basin include a range of differently-sized channels, thus creating the potential for more varied geometric response. Upland reservoirs that regulated downstream flow in Heitmuller (2014) are absent along the rivers in this study area. Ziliani and Surian (2012) acknowledge that reliable and detailed reconstruction of channel changes is attainable when in a specified timeframe there are a “significant number of measurements of one or more channel features (e.g., channel width and bed elevation)” (Ziliani and Surian, 2012 p. 109). Further, identification of cause is easier in rivers where dramatic changes are observable in a short time period and in those with a limited range of factors effecting channel processes at catchment and reach scale. The methods and study area for this paper comply with these conditions.

CHAPTER III

METHODS

The methods discussed below were employed to retrieve and analyze historical cross-sectional data for the Pascagoula River basin and adjacent fluvial systems. The various stages required to produce profiles for analysis are reflected in the intent of each method toward data acquisition, data processing, or data analysis.

Data Acquisition

Channel shape (cross-sectional) assessments require (1) elevation measurements of the channel bed and banks at a consistent location through time and (2) documentation of the reference elevation datum, whether geographic (e.g., North American Vertical Datum of 1929) or arbitrary (site specific). The U.S. Geological Survey (USGS) Water Science Center in Jackson, Mississippi maintains a number of streamflow-gaging stations in the proposed study area (Figure 1), a number of which have more than 30 year periods-of-record. At each station, hydrologic technicians periodically measure depth and velocity at pre-defined width increments across the channel. To derive elevation values for the bed and banks technicians subtract the recorded depths from the weighted mean gage height (an average of the water-surface elevation at different times throughout the measurement). The measurement locations, depth, and mean gage height values are recorded on a formatted sheet (Figure 3).

The USGS has made these data publicly available for various periods of record, summarized in the web-based USGS National Water Information System (NWIS) (U.S. Geological Survey, 2008). The NWIS database provides only discharge summary and total width and mean depth information. The original hardcover field notes archived at

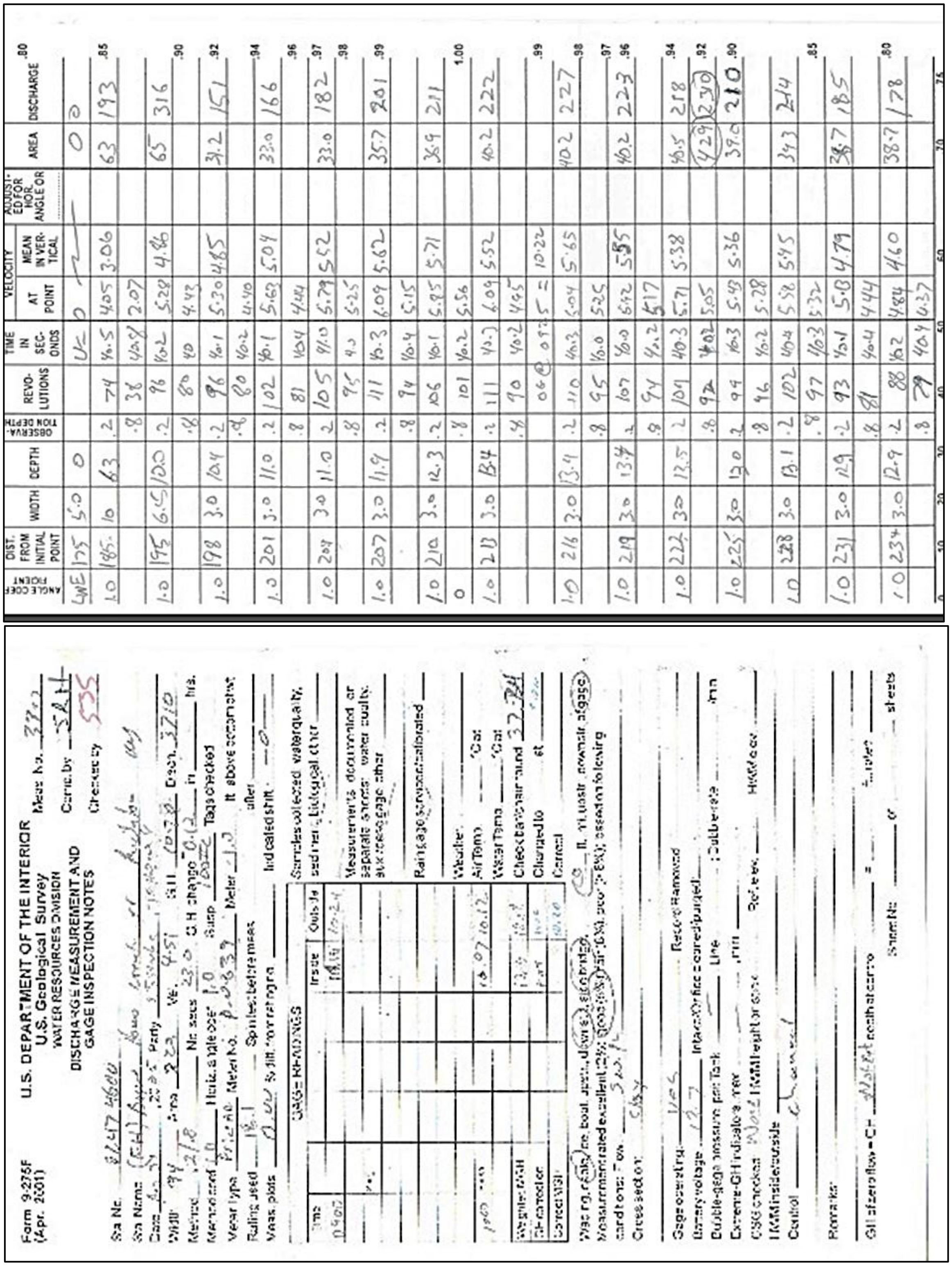


Figure 3. Example of a hardcopy field measurement collected at U.S. Geological Survey gaging station and archived in Jackson, MS. Example report was collected at Bogue Homo near Richton, MS (02474600).

the USGS office include water-surface width, flow depth, and flow velocity; these are required to quantify complete cross-sectional channel geometry through time (Juracek and Fitzpatrick, 2008). The data used in this study were obtained from the original hard-copy notes maintained in the archive. This was done via photocopying and subsequent manual entry of the original measurements into an excel database.

These periodic measurements have occurred at varying discharge levels from low-flow to flood-stage events. Only measurements taken during moderate discharge events, many approximating bank full flow, were considered. Low-flow measurements are useful for indicating bed incision; however, for a complete channel cross-section, bank adjustments were also portrayed.

Data Processing

Incremental width and depth data were transferred from the photocopied reports into a Microsoft Excel spreadsheet. In a separate column the depth was subtracted from the weighted mean gage height given on the report. This new value represented the channel bed elevation. The cross channel distance and bed elevation (in feet) were plotted together; the resulting graph depicted the cross-sectional channel form. Channel cross-sections were then superimposed to demonstrate changes over the duration of the study period.

The cross channel distance and bed elevation data from each gaging station were transferred into a .txt file via Notepad, then imported into WinXSPRO, a free software program provided by the U.S. Department of Agriculture, Forest Service (2005). WinXSPRO calculates changes to cross-sectional area (among other hydraulic variables) of a channel between user-specified stage increments, then displays the data in tabular form. Channel slope is necessary for the non-geometric hydraulic calculations (e.g., mean velocity, Froude number). Channel slopes were calculated from distance and elevation measurements obtained on Google Earth. This added a quantitative component to the observed changes in channel form. Frequent mention is made throughout the results and discussion section to stage levels. WinXSPRO zeroes out each profile at the deepest channel position and, from there, calculations are made at every 1-foot stage. Lower single digit stages will often refer to the channel bed, while higher double digit stage levels will often refer to intervals near the bankfull stage.

Data Analysis

The cross-sectional channel forms were once more rendered using the TKG2 graphing program developed by William H. Asquith, of the U.S. Geological Survey, and Texas Water Science Center. TKG2 graphing program inputs .txt files and generates publication-quality graphs offering more defined channel forms.

A request, in accordance with the Freedom of Information Act (FOIA), was submitted to the Mississippi Department of Environmental Quality's (MDEQ) permitting department to ascertain an accurate timeline of economic and resource extraction projects along each of the rivers in the study area (Appendix A). Any project within the study duration could have been an important allogenic driver in observed channel form change. Through communication with the director Michael Bograd (e.g., e-mail and discussion) it was discovered that with the exception of the Leaf and Bouie Rivers, permits were not administered within the Pascagoula River basin for aggregate mining.

Channel profiles were cross-referenced with available data resources to identify any possible influences on channel form. The National Water Information System

(NWIS) (U.S. Geological Survey, 2008) was used to characterize the location of the gaging station and any arbitrary vertical datum adjustments that were made by technicians. It is the source of all flow information referenced throughout this paper, including peak annual discharge (ft^3/s).

The National Bridge Inventory Database (Nationalbridges.com, 2013) identified dates of new bridge construction and, therefore, gage location. Additionally, information on any bridge reconstruction that would have influenced channel hydraulics was noted.

CHAPTER IV

RESULTS AND DISCUSSION

Historical cross-sectional adjustments in the Pascagoula River basin and adjacent fluvial systems are presented in order according to their USGS station ID number. Increasing ID number generally reflects an upstream to downstream progression through the basin.

Leaf River near Collins (02472000)

Figure 4. Site location along Leaf River near Collins, MS. U.S. Geological Survey streamflow-gaging station 02472000 is marked by grey indicator (ESRI 2014).

The profiles for the gaging station on the Leaf River near Collins (Figure 4) were divided into periods A (1944–1976) and B (1987–2003) (Figure 5) based on new bridge construction. Period A is characterized by a trend toward smaller channel area. The profile in 1976 has 25% less cross-sectional area than that of the 1950 measurement. Bank accretion narrowed the fluvial system approximately 70 feet, while the contemporaneous removal of channel bar deposits led to the inconsistent lowering of bed elevation. The resulting uneven bed form was not able to account for the overall narrowing, observed between 1950 and 1966 (Table 1). Noteworthy is the similarity in the cross-sectional forms of 1966 and 1976, before and after 1974 historic flooding (54,200 ft^3/s).

Following gage relocation the new channel profile featured steeper banks and a trend towards a broader, moderately less undulating bed form. This is demonstrated by comparing cross-sectional area for stages 1–5 between both periods. This value was 100% greater in 2003, 85% greater in 1987, and 20% greater in 1994 than the average for period A. Relative stability in positioning of the banks, with greater adjustment occurring along the channel bed would comply with Mossa and Coley’s (2004) evaluation of the Leaf River as having mostly stable positioning downstream. Additionally, the reach of the Leaf near Collins does not appear to have the range of adjustments usually attributed to in-channel mining.

Floodplain accretion also occurred on both the right and left banks. Vertical accretion along the banks and floodplains in Heitmuller (2014) was indicative of vegetation advancement along the banks. Considering the banks in Figure 25 dense vegetation appears to be holding in the areas immediately adjacent to the river channel.

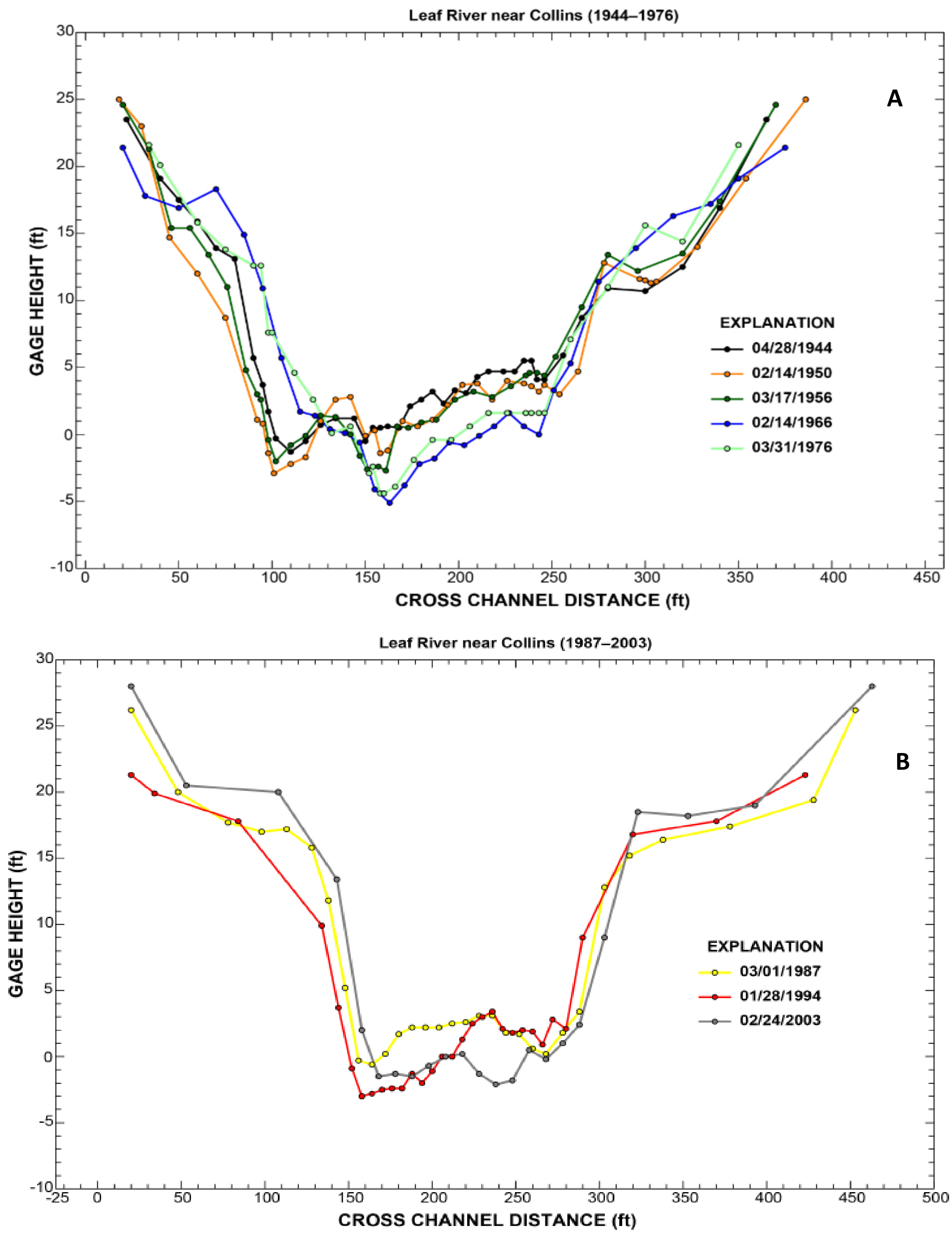


Figure 5. Cross-sectional profiles summarizing historical channel adjustments for the Leaf River near Collins (USGS 02472000). (A) Gage location from 1944–1976 (B) Gage location from 1987–2003. Cross-section view is downstream, (A) x-axis is from right-water-edge; (B) x-axis is from left-water-edge.

Table 1

Spatial and Hydraulic Values Calculated from WINXSPRO for the Leaf River near Collins

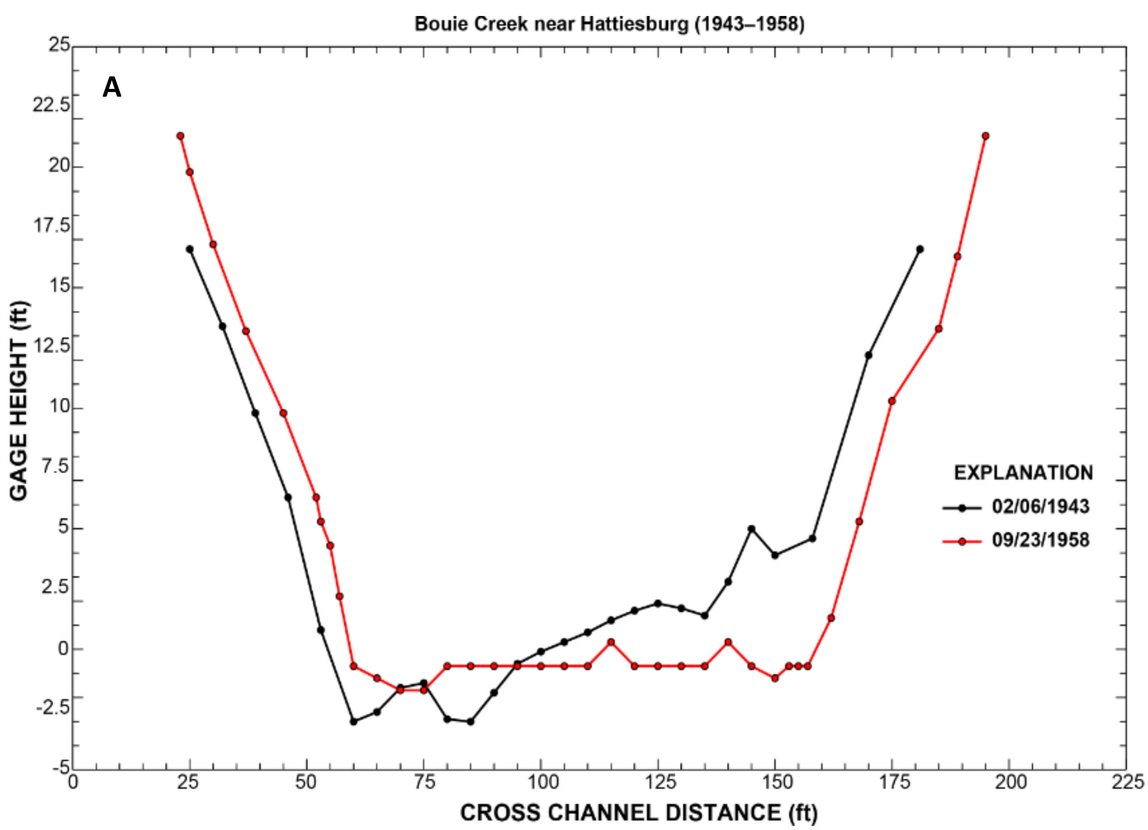
Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1950	20	3428.65	303.14	0.0003	4.25	14567
1966	20	2562.42	218.33	0.0003	4.36	11161
1987	20	3249.75	372.17	0.0003	-	-
1994	20	2767.12	240.94	0.0003	-	-
2003	20	2865.07	202.60	0.0003	-	-

Bouie Creek near Hattiesburg (02472500)

Figure 6. Site location along Bouie Creek near Hattiesburg, MS. U.S. Geological Survey streamflow-gaging station 02472500 is marked with a grey indicator (ESRI 2014).

Several evolutions of channel form take place at this gaging station during the study period (1943–2011). Construction of a new bridge around 1959 resulted in relocation of the gage, with an identifiable thalweg and point bar, to a straighter reach, producing a symmetrical channel profile. Bridge reconstruction in 1993 required a separation of the cross sections into periods A (1943–1958), B (1966–1985), and C (1997–2011). Period B shows overall narrower and more stable bank positions, despite a near record flood event in 1974 (45,000 (ft^3/s). The 1985 measurement has a lower mid-channel bed elevation by 4 feet. Cross-section C is characterized by having no trend towards a specific form or geometry; however, the 2011 measurement does show accretion to both upper banks. A combination of bank erosion/aggradation events and the contemporaneous development and removal of bed forms are responsible for the range of area and width values calculated in Table 2.

Mossa and Coley (2004) characterized the Bowie River as unstable (cross-sectional area increases of 400% –500% during the 1940s and 1950s) due to in-stream and floodplain channel mining and the appearance of flooded pits. This study focused on the Bouie Creek reach at the confluence with the Okatoma. Where they join to form the Bowie River is upstream from the historical mining operations and, therefore, not influenced by activity, causing general stability.



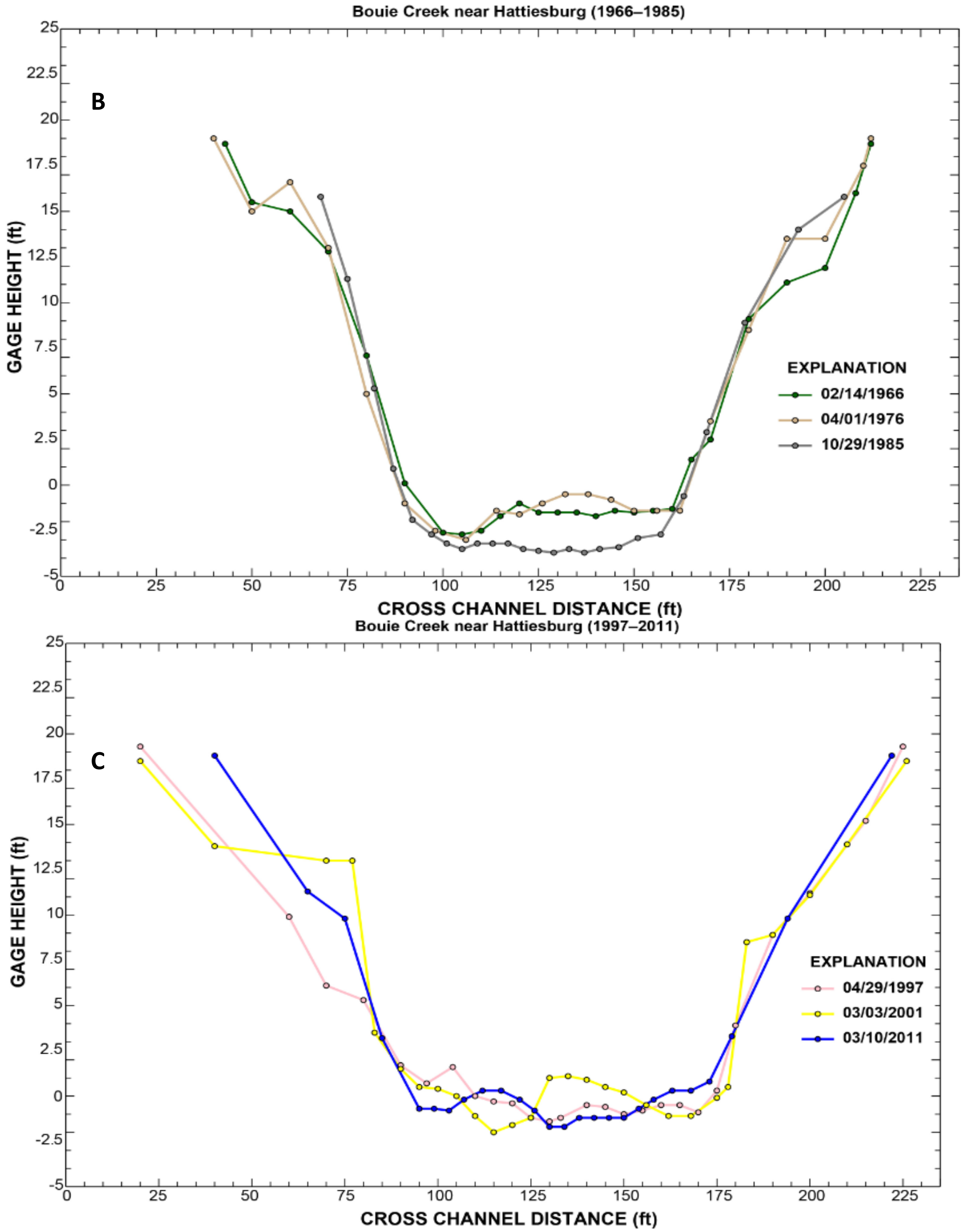


Figure 7. Cross-sectional profiles summarizing historical channel adjustments for the Bouie Creek near Hattiesburg (USGS 02472500). (A) Gage location 1943–1958. (B) Gage location 1966–1985. (C) Gage location 1997–2011. Cross-section view is downstream, (A) x-axis is distance from left-water edge, in (B) and (C) x-axis is distance from right-water-edge.

Table 2

Spatial and Hydraulic Values Calculated from WINXSPRO for Bouie Creek near Hattiesburg.

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1943	15	1353.19	134.96	0.0005	4.77	6452
1958	15	1674.41	148.19	0.0005	5.17	8652
1976	15	1259.67	115.75	0.0005	5.01	6305
1997	15	1620.53	164.74	0.0005	4.79	7757
2001	15	1374.20	129.79	0.0005	4.85	6669
2011	15	1488.77	146.56	0.0005	4.87	7245

Leaf River at Hattiesburg (02473000)

Figure 8. Site location along Leaf River at Hattiesburg. U.S. Geological Survey streamflow-gaging station 02473000 is marked by grey indicator (ESRI 2014).

The cross-sectional profiles for the Leaf River at Hattiesburg occur at two different channel positions. The first change in channel form is a result of new bridge construction. The relocation is likely responsible for the dramatic increase in area (60%) over duration of the study, marked by deep incision (up to 15 feet).

However, bridge relocation is not the only anthropogenic forcing of channel geometry change for this location. The 1975 measurement, prior to relocation, demonstrates 3–4 feet of incision. The 1987 profile following relocation appears to also be in an incised state. From 1993–2011 bed aggradation of 2–4 feet and subsequent left bank erosion expanded the channel width (32 ft.) and area (7%).

Mossa and Coley (2004) accurately depict the Leaf River as unstable, especially in this gage location, downstream adjacent to the confluence the Bowie and Leaf Rivers. Both rivers have a history of considerable in-channel mining projects (Rasmussen and Mossa, 2011; Grimball and Heitmuller, 2012). In-channel mining is a common source of incision for alluvial streams. The rate of aggradation as a response to incision is well within the 0–12 meters postulated in Simon (1989) downstream from the disturbance and at a channel mouth.

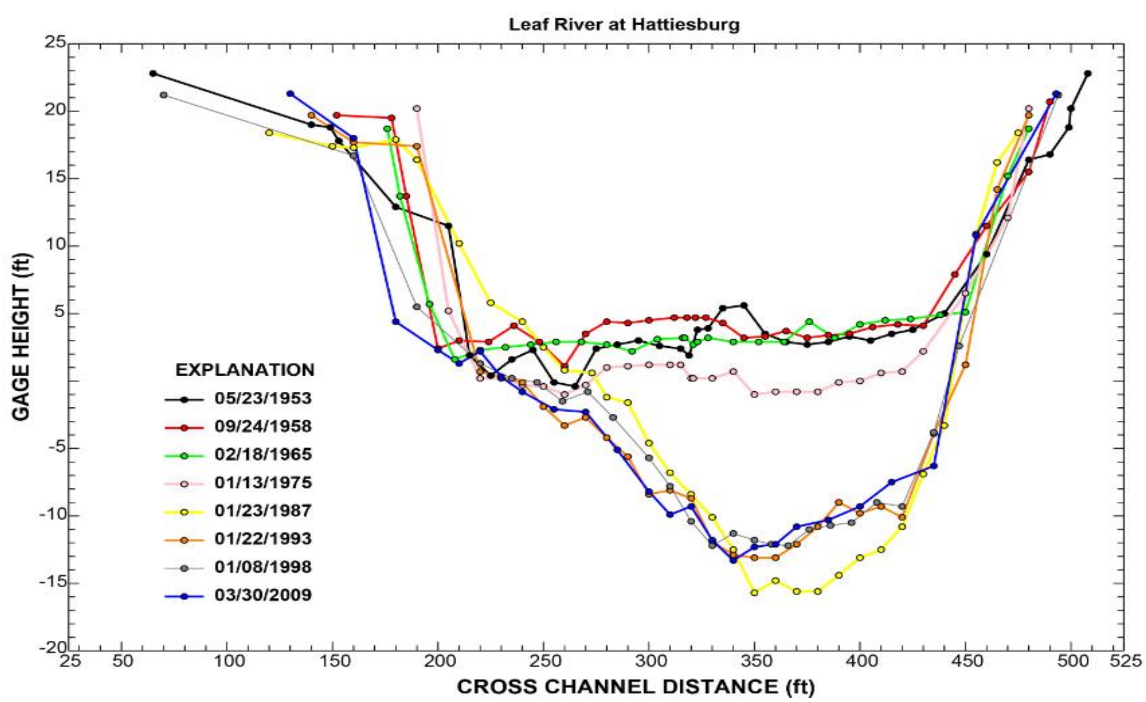


Figure 9. Cross-sectional profile summarizing historical channel adjustments for the Leaf River at Hattiesburg (USGS 02473000). Cross-section view is downstream, x-axis is distance from left-water-edge.

Table 3

Spatial and Hydraulic Values Calculated from WINXSPRO for the Leaf River at Hattiesburg

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1953	15	2994.29	304.22	0.0002	2.75	8234
1965	15	3612.49	295.48	0.0002	3.18	11485
1987	25	3626.23	240.24	0.0002	3.62	13123
1998	25	4854.42	302.33	0.0002	3.81	18484

East Tallahala Creek at Waldrup (02473460)

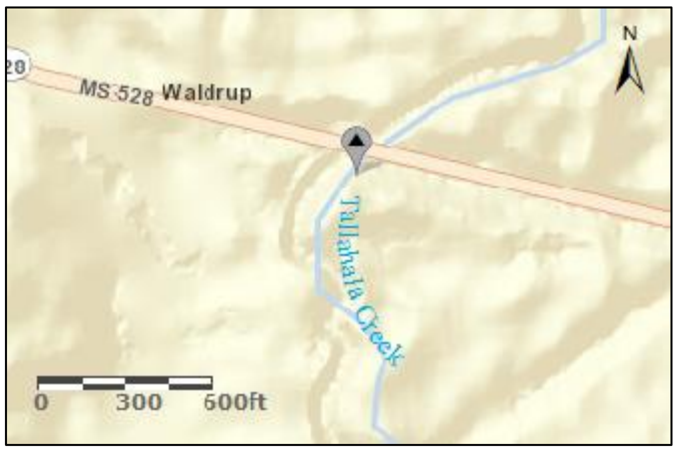


Figure 10. Site location along East Tallahala Creek at Waldrup. U.S. Geological Survey streamflow-gaging station 02473460 is marked with a grey indicator (ESRI 2014).

The Tallahala Creek at gaging station 02473460 consistently trends toward lowering of bed elevation. Mechanisms for observed gradual lowering appear to be thalweg incision toward the right bank and simultaneous depression formation at the base of the left bank from 1964–1993. The decrease in area after 1993 appears connected to infilling of the aforementioned depression. The thalweg remains structurally sound during this period. Over the study period the channel also trends toward point bar vertical accretion of approximately 3 feet, protrusion of approximately 15 feet from the left bank, and floodplain accretion of approximately 2 feet adjacent to the right bank. This growth is similar in trend again to vertical accretion along the banks and floodplains in

Heitmuller (2014), which indicated vegetation advancement along the banks. Coincidentally, the channel was not able to be cleanly photographed for Figure 39 due to overgrowth.

The 1979 incision anomaly of around 15 feet accurately represents the data recorded on the hardcopy flow report. This anomaly appears too narrow to be a natural occurrence and is not associated with any significant hydrologic event.

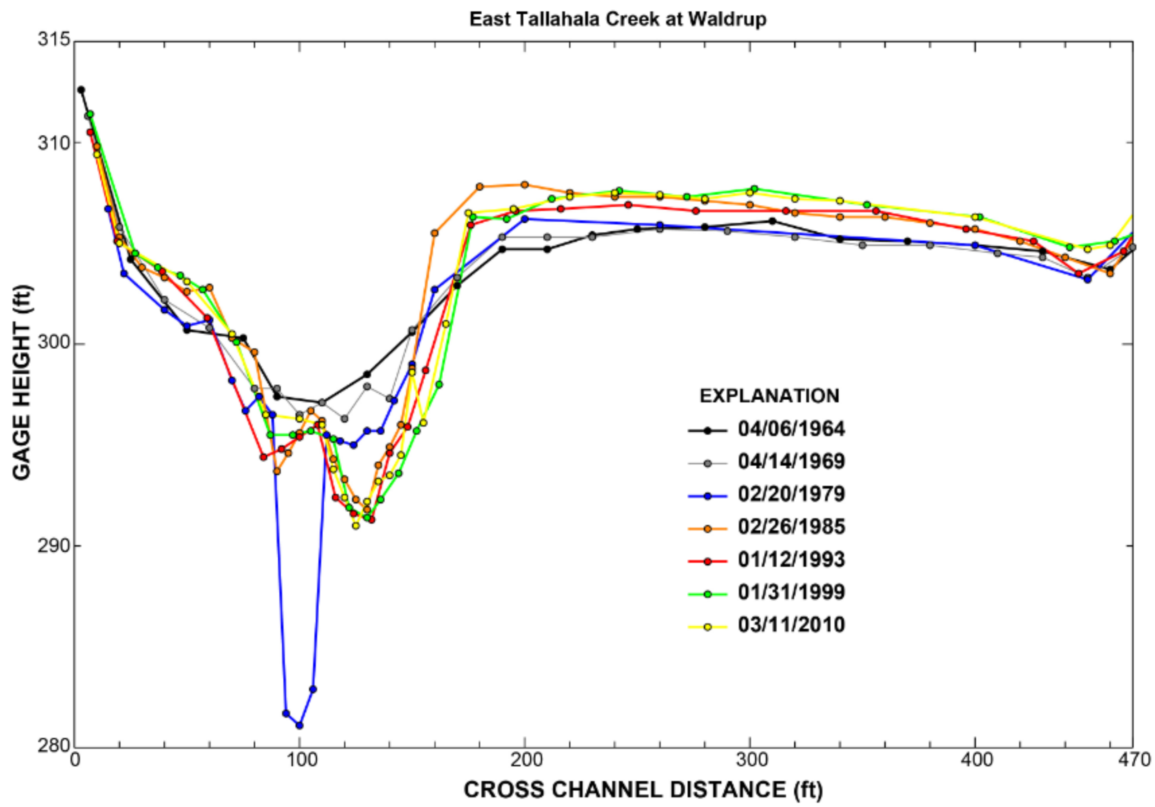


Figure 11. Cross-sectional profile summarizing historical channel adjustments for Tallahala Creek at Waldrup (USGS 02473460). Cross-section view is downstream, x-axis is distance from left-water-edge.

Table 4

Spatial and Hydraulic Values Calculated from WINXSPRO for Tallahala Creek at Waldrup.

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1964	8	845.48	303.27	0.0011	3.25	2751
1979	24	1283.09	263.22	0.0011	4.41	5663
1993	14	1163.22	209.28	0.0011	-	-
2010	14	988.73	172.31	0.0011	-	-

Tallahala Creek at Laurel (02473500)

Figure 12. Site location along Tallahala Creek at Laurel, MS. U.S. Geological Survey streamflow-gaging station 02473500 is marked by a grey indicator (ESRI 2014).

The main channel form remains stable for most of the study duration with a significant change in area coming from the growth and subsequent infilling of secondary channels. From 1947 to 1966 the main channel remains nearly identical, while the fluvial system's overall area expanded 26%.

The infill and disappearance of these secondary channels coincides with incision of the main channel 5 feet from 1990 until 2011. At the end of this study period the incision based increase in main channel area was 353 sq ft. This increase left a net loss of 86.4 sq ft. from 1982 and 338.7 sq ft. from 1966. The adjustment in channel geometry would seemingly leave this reach of Tallahala Creek unable to handle large pulse events without significant overland flow.

Burnett and Schumm (1983) attributed neotectonic uplift of the Wiggins anticline to variation in regional river morphology. Among the observed variations was pattern alteration as a meandering stream crossed the axis of uplift. Upstream from the fold axis a meandering channel is shown to evolve several anastomosing secondary channels as a response to lowered gradient. Additionally, channel bed aggradation would result from the reduced stream power. Downstream the river continues in its initial meander pattern. This pattern is reversed for synforms (Holbrook and Schumm, 1999). Location of Tallahala Creek at Laurel upstream from the axis would explain the presence of secondary channels and bed aggradation from 1940-1982. A possible mechanism for the infill of these secondary channels is expansion of the Laurel, Mississippi urban area during the 1980s.

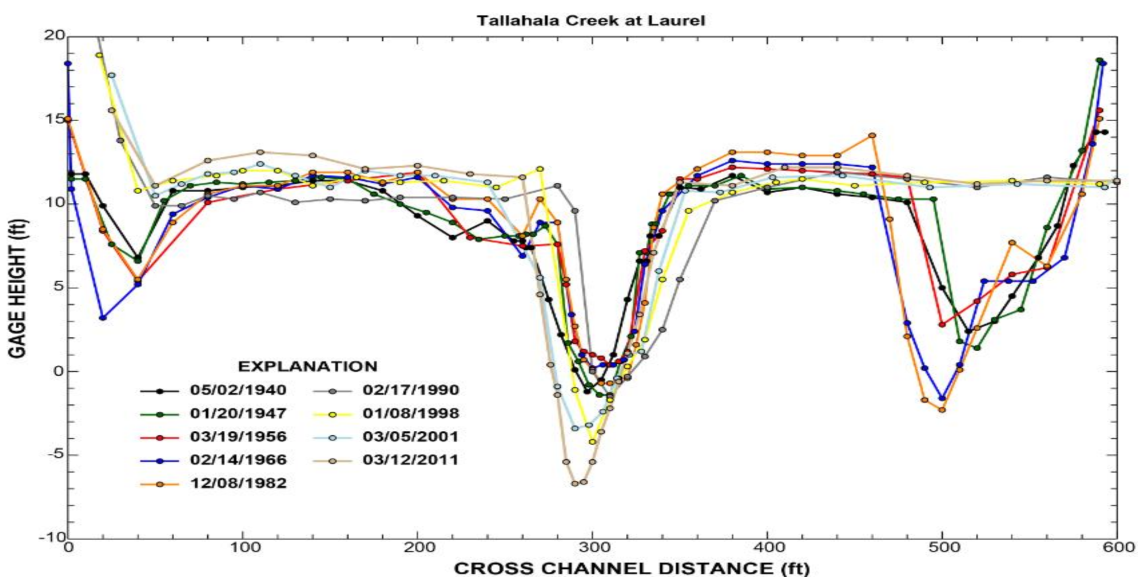


Figure 13. Cross-sectional profile summarizing historical channel adjustments for Tallahala Creek at Laurel (USGS 02473500). Cross-section view is downstream, x-axis is distance from right-water-edge.

Table 5

Spatial and Hydraulic Values Calculated from WINXSPRO for Tallahala Creek at Laurel.

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1947	11	952.30	245.72	0.0003	1.99	1890
1956	11	1549.31	391.06	0.0003	2.04	3161
1966	11	1204.22	262.48	0.0003	2.22	2678
1982	11	951.93	203.16	0.0003	2.11	2006
1990	11	512.55	76.92	0.0003	2.71	1388
1998	14	629.21	86.06	0.0003	3.01	1892
2001	14	831.98	111.18	0.0003	3.18	2648
2011	18	865.59	130.18	0.0003	2.92	2528

Tallahala Creek near Runnelstown (02474500)

Figure 14. Site location along Tallahala Creek near Runnelstown, MS U.S. Geological Survey streamflow-gaging station 02474500 is marked by a grey indicator (ESRI 2014).

Channel adjustments at gaging station 02474500 are observed to occur along the left bank. Thalweg position through time has maintained a relatively steep and stable right bank. In profiles 1998 and 2009 the slope of the right bank increased. Subsequent hingepoint development (Heitmuller, 2014) and proliferation occurred at the base of the new left bank, and point bar accretion developed at the top. Restructuring of the right bank accounts for the 14% loss in cross-sectional area and 15% decrease in width during the study period.

Is it possible that reinforcement of the left bank occurred to protect the roadway on the lower profile side. It appears from the cross section and is suggested by WinXSPRO that preferential widening was occurring in stages 15—20 in 1987. The channel is wider in that stage interval than at any other measurement during the study period. A continuation of that trend into the early 1990s would have resulted in the hypothesized artificial reinforcement response observed in the mid 1990s.

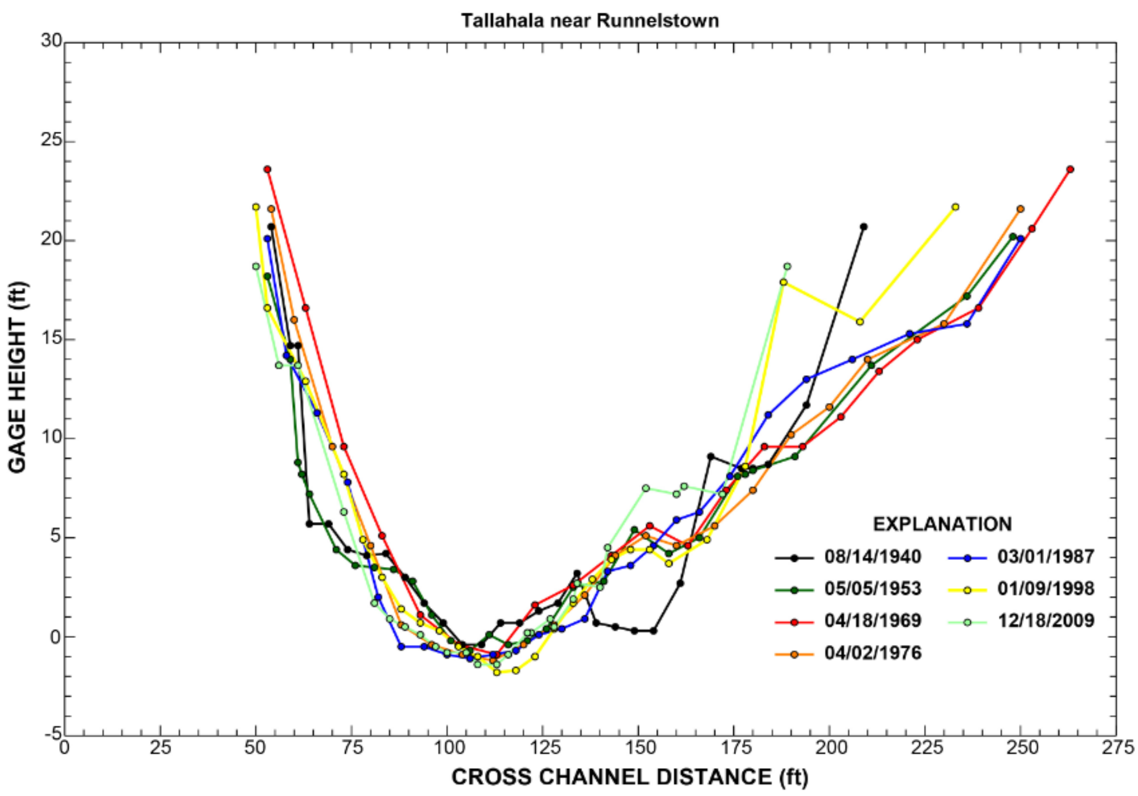


Figure 15. Cross-sectional profile summarizing historical channel adjustments for Tallahala Creek near Runnelstown (USGS 02474500). Cross-section view is downstream, x-axis is distance from right-water-edge.

Table 6

Spatial and Hydraulic Values Calculated from WINXSPRO for Tallahala Creek near Runnelstown

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1969	20	2125.20	188.32	0.0006	6.02	12798
1987	20	2171.40	192.08	0.0006	6.01	13056
1998	20	1859.40	165.85	0.0006	-	-
2009	20	1818.46	138.73	0.0006	-	-

Bogue Homo near Richton (02474600)

Figure 16. Site location along Bogue Homo near Richton, MS. U.S. Geological Survey streamflow-gaging station 02474600 is marked with a grey indicator (ESRI 2014).

Gage placement on a straight reach of the stream has yielded a nearly symmetrical channel profile. Construction of a new bridge in 1987 repositioned the channel and required the profiles to be separated into periods A and B. Period B (1993–2005) trends toward a narrower channel and lower bed elevation. Change in channel form does not appear to be a direct result of the bridge reconstruction. The profile of the 1985 measurement shows the development of an incised channel bed two years before gage relocation. Over the course of the study, the channel bed elevation lowers, while 27% of width is lost with an 18% decrease in area. These adjustments are contrary to the expected development of the channel and are possibly linked to in-stream aggregate mining. This section of the Bogue Homo is upstream from the axis of uplift detailed in Burnett and Schumm (1983). The slope should be reduced at the gage location, resulting in decreased erosion, not incision. The 1993 profile seems to depict accretion on the upper left bank. This was unable to be confirmed in 2005, as the channel did not appear to be at bank full stage.

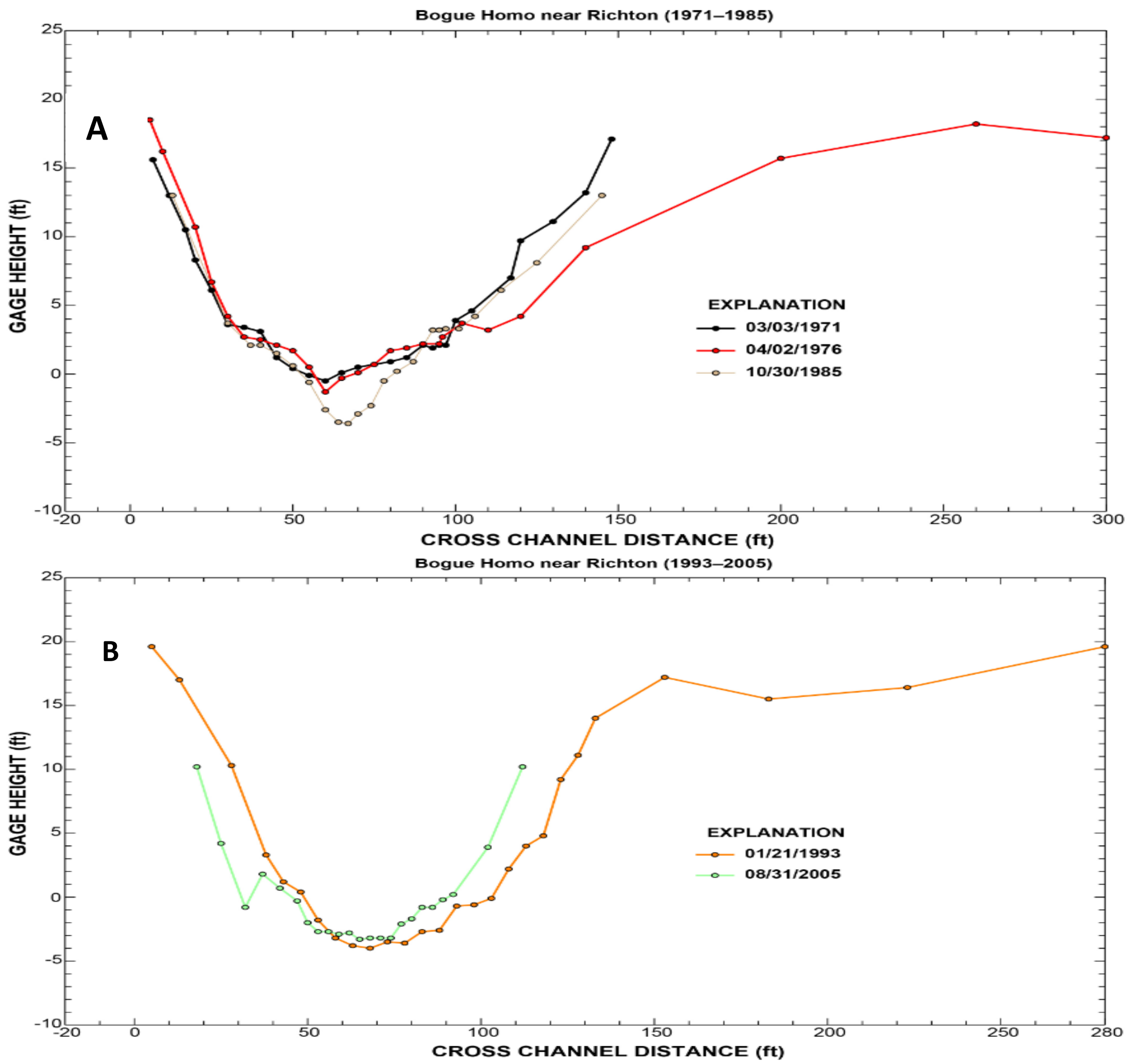


Figure 17. Cross-sectional profiles summarizing historical channel adjustments for the Bogue Homo near Richton (USGS 02479600). (A) Gage location 1971-1985. (B) Gage location 1993–2005. Cross-section view is downstream, (A) x-axis is distance from the left-water-edge (B) x-axis is from the right-water-edge.

Table 7

Spatial and Hydraulic Values Calculated from WINXSPRO for Bogue Homo near Richton.

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (^{3}/s)
1971	14	1147.78	129.58	0.001	6.33	7270
1985	14	876.97	116.64	0.001	5.69	4989
1993	14	921.66	96.68	0.001	-	-
2005	14	937.70	94.00	0.001	-	-

Leaf River near McLain (02475000)

Figure 18. Site location along the Leaf River near McLain, MS. Old U.S. Geological Survey streamflow-gaging station is marked with grey indicator; current position for 02475000 is highlighted in yellow box (ESRI 2014).

Profiles for this reach of the Leaf River were divided into periods A (1941–1983) and B (1993–2002) in accordance with new bridge construction and the relocation of the gage 0.3 miles upstream. This cross-sectional profile demonstrates the opposite development from the reach of the Leaf River located near Collins. From 1941 to 1959, period A chronicles the modification of a chute channel into a point bar through infill, the resulting rightward thalweg migration, and widening of the channel approximately 100 feet through erosion of the right bank. From 1967 through 1983 the point bar is then deconstructed and channel bed elevation lowered within a range of 1 to 2 feet adjacent the right bank and up to 10 feet adjacent the left bank. These developments are explained by Rasmussen and Mossa (2011) as a function of in-channel mining, located either well upstream in the Bowie River or in situ. They noted that removal of large aggregates and the creation of pits to trap coarse particles in the Bowie translated to 78% of bed material in the Leaf being finer than 2 mm. The Leaf River's bed would not have been sufficiently armored, leading to more mobile, less permanent bed and bar features. Material extraction directly at the point bar, which would have had a similar result, is more plausible, considering that the Bouie River is too far upstream to influence this site. Coarser material selectively removed would have exposed remaining fines for erosion while preventing any further bar development. Although the effects from in-channel mining are observed at this gaging station they did not reach the full extent, increased width and depth, which were accepted by Rasmussen and Mossa (2011) at their location.

The profile across period B shows the similar transition of a divided main channel to one with a substantial point bar growth (Figure 30) and leftward thalweg migration. The end of permissible in-channel mining by MDEQ would suggest this point bar is less mobile and more of a persistent feature. It also appears likely that the left bank was artificially stabilized to protect the major throughway of State Highway 98.

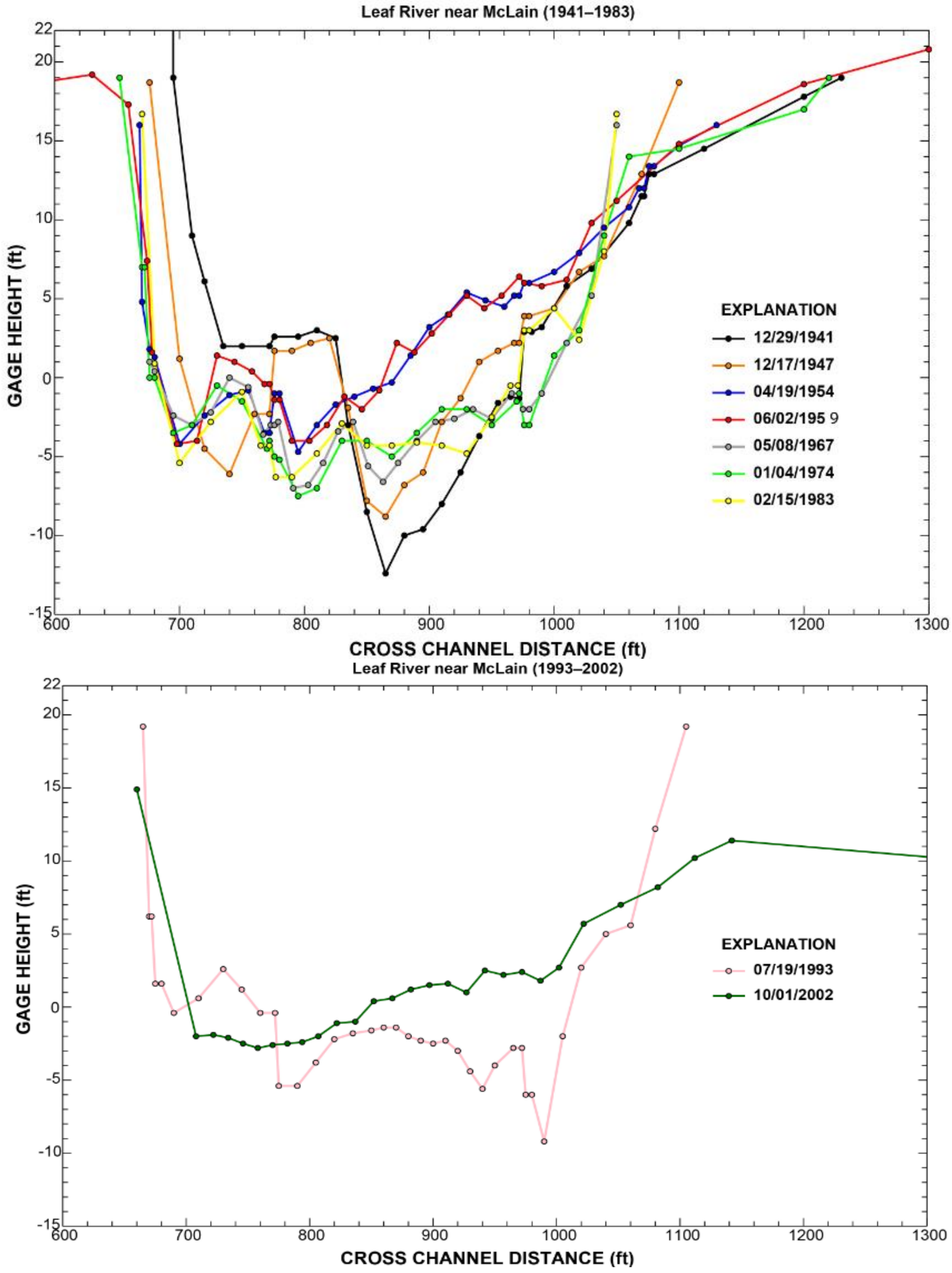


Figure 19. Cross-sectional profiles summarizing historical channel adjustments for the Leaf River near McLain (USGS 02475000). (A) Gage location from 1941–1983. (B) Gage location from 1993–2002. Cross-section view is downstream, x-axis is distance from the right-water-edge.

Table 8

Spatial and Hydraulic Values Calculated from WINXSPRO for the Leaf River near McLain

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1947	20	4159.95	373.91	0.0002	2.98	12401
1959	20	5441.73	510.28	0.0002	2.91	15848
1974	20	5514.58	392.25	0.0002	3.49	19222
1983	20	5813.01	374.65	0.0002	3.70	21479
1993	20	4776.98	407.53	0.0002	3.07	14643

Chunky River near Chunky (02475500)

Figure 20. Site location along Chunky River near Chunky, MS U.S. Geological Survey streamflow-gaging station 02475500 is marked with grey indicator (ESRI 2014).

Channel form at this gaging station is symmetrical despite positioning at a bend. The data analyzed had a variable range of discharge values for the duration of the study period (1946–2009). Alternating peak discharge levels ranging from 4,000 (ft3/s) to 30,000 (ft^3/s) exacerbate the scour and fill mechanics of the Chunky River. Like many alluvial channels, a temporary scour and fill cycle was also observed in Black Creek near Wiggins. There, more conservative fluctuations in discharge lessened the effects. While the bed elevation was continuously adjusted by temporary scour-and-fill, bank position and, therefore, channel position demonstrated greater stability than Black Creek. This reach of the Chunky River widened following bridge renovation in 1994.

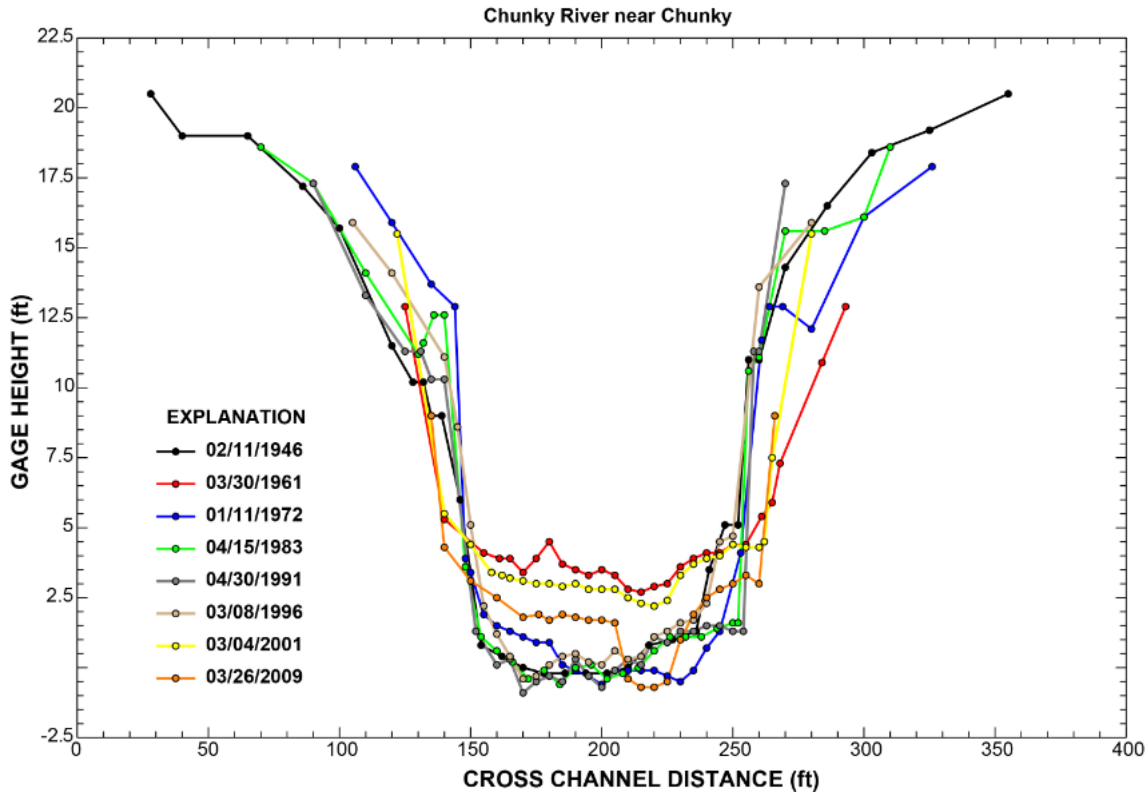


Figure 21. Cross-sectional profile summarizing historical channel adjustments for the Chunky River near Chunky (USGS 02475500). Cross-section view is downstream, x-axis is distance from the right-water-edge.

Table 9:

Spatial and Hydraulic Values Calculated from WINXSPRO for the Chunky River at Chunky.

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1946	12	1219.93	143.85	0.0006	4.50	5492
1972	12	1166.40	116.02	0.0006	4.95	5770
1991	12	1179.49	126.12	0.0006	4.70	5541
2001	12	1453.80	153.22	0.0006	5.17	7519
2009	12	1190.00	131.00	0.0006	4.90	5831

Chickasawhay River at Enterprise (02477000)

Figure 22. Site location along the Chickasawhay River at Enterprise, MS. U.S. Geological Survey streamflow-gaging station 02477000 is marked with a grey indicator (ESRI 2014).

The graph depicting the 1946 and 1956 measurements was adjusted up 5 feet, according to a datum adjustment in 1967 (NWIS) (U.S. Geological Survey, 2008).

The Chickasawhay River at Enterprise gage station occurs along a straight reach of the river. This would be expected for the stations along the Chickasawhay River. Mossa and Coley (2004) suggested the Chickasawhay would have greater than 60% non-sinuous portions. The increase in width represented in Table 7 from 1991–2001 is exaggerated by the development of a smooth floodplain after the infill of secondary channels. Considering the cross-section at the ten foot stage, where just the main channel is accounted for, the width is decreasing after 1980. This is a result of the absence of a previously vertically accreted channel bar and a steeper left bank. In 1980 the maximum growth of the channel bar diverted flow towards the right bank causing it to extend past the typical position observed in the other measurements. Similar bank erosion is mentioned in Curran (2010) as a result of impounded LWD. The immediate banks along the Chickasawhay are heavily forested, which explains the potential for LWD in the channel at this station. The removal of the bar after 1980 not only returned the right bank to its original position, but it also increased the main channel area. Evidence for this is given by the increase in area 8% in stages 1–5 after 1980. The absence of the bar is most likely the result of a new bridge constructed just 20 feet from the original in 1986. Contemporaneous with the removal of the channel bar is the vertical accretion observed on the left bank.

The stable position of the main channel from 1946–2001 is in accordance with Mossa and Coley's (2004) characterization of straight reaches of the Chickasawhay River. According to their report, straight sections crossed cohesive mudstones and were less prone to changes or migration.

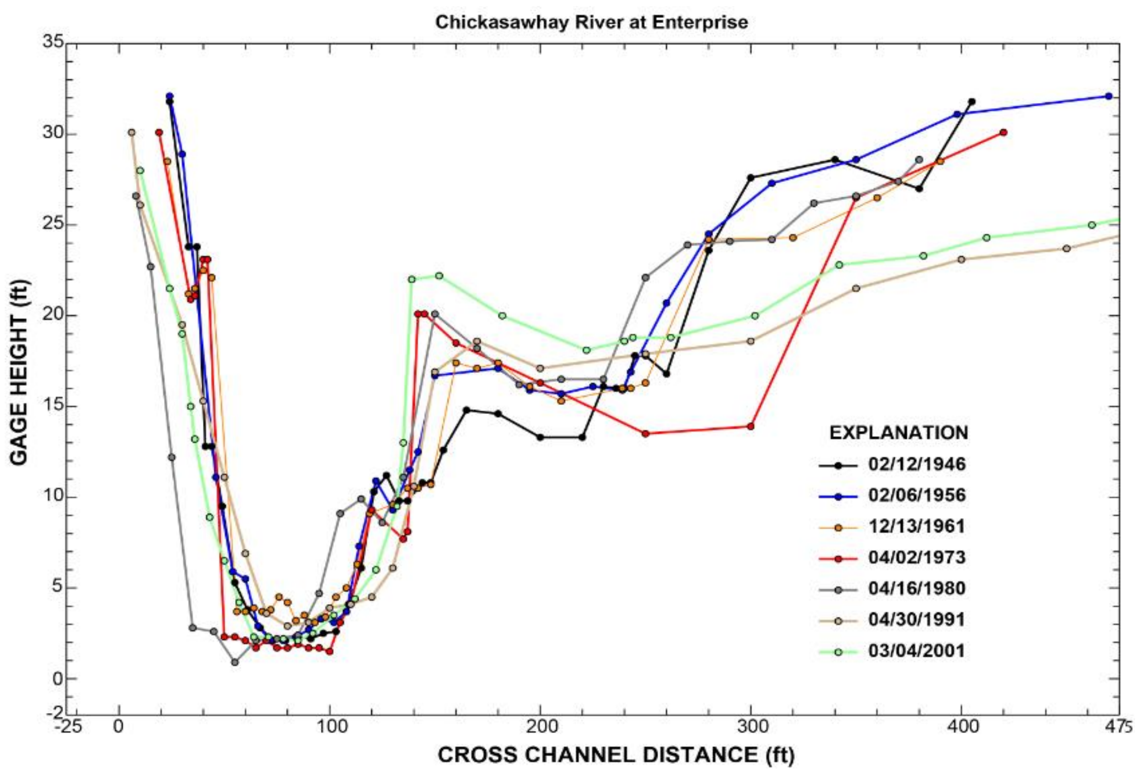


Figure 23. Cross-sectional profile summarizing historical channel adjustments for the Chickasawhay River at Enterprise (USGS 02477000). Cross-section view is downstream, x-axis is distance from the right-water-edge.

Table 10

Spatial and Hydraulic Values Calculated from WINXSPRO for the Chickasawhay River near Enterprise.

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1946	20	2605.78	237.97	0.0002	2.63	6850
1956	20	2274.34	231.26	0.0002	2.46	5593
1973	20	2681.85	291.32	0.0002	2.30	6173
1980	20	2167.61	229.00	0.0002	2.39	5175
1991	20	2792.64	374.05	0.0002	2.09	5828
2001	20	2199.38	301.43	0.0002	-	-

Buckatunna Creek near Denham (02477990)

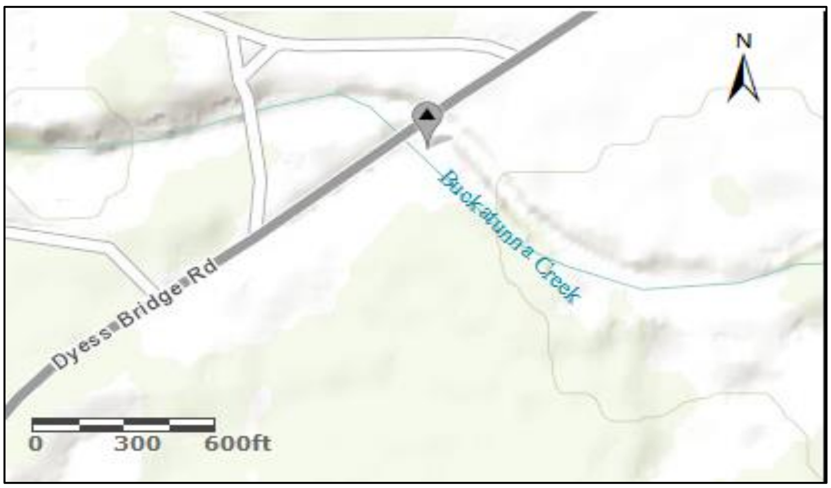


Figure 24. Site location along Buckatunna Creek near Denham, MS. U.S. Geological Survey streamflow-gaging station 02477990 is marked with a grey indicator (ESRI 2014).

The channel form for the Buckatunna Creek near Denham remains largely unaltered. Specifically, the channel form lost 1% of its cross-sectional area from 1973–2009. The symmetry of the channel is a result of the straight reach of river on which the gage is established. Relative stability observed in the banks and consistency of the channel bed most likely result from interaction with the Yazoo Clay unit of the Jackson Group. The Buckatunna is known to drain the Yazoo Clay that outcrops in this area. The cohesive clay unit would be less susceptible to geometric changes from hydrologic pulses. The perceived closing-in during the 1999 measurement could possibly be attributed to a large availability of sediment associated with 1998 Hurricane Georges flooding. However, peak discharge events are also minimal for this channel. Since 1990 no peak discharge event had been recorded at greater than 9,000 (ft^3/s); most fell within a 4,000–6,000 (ft^3/s) range.

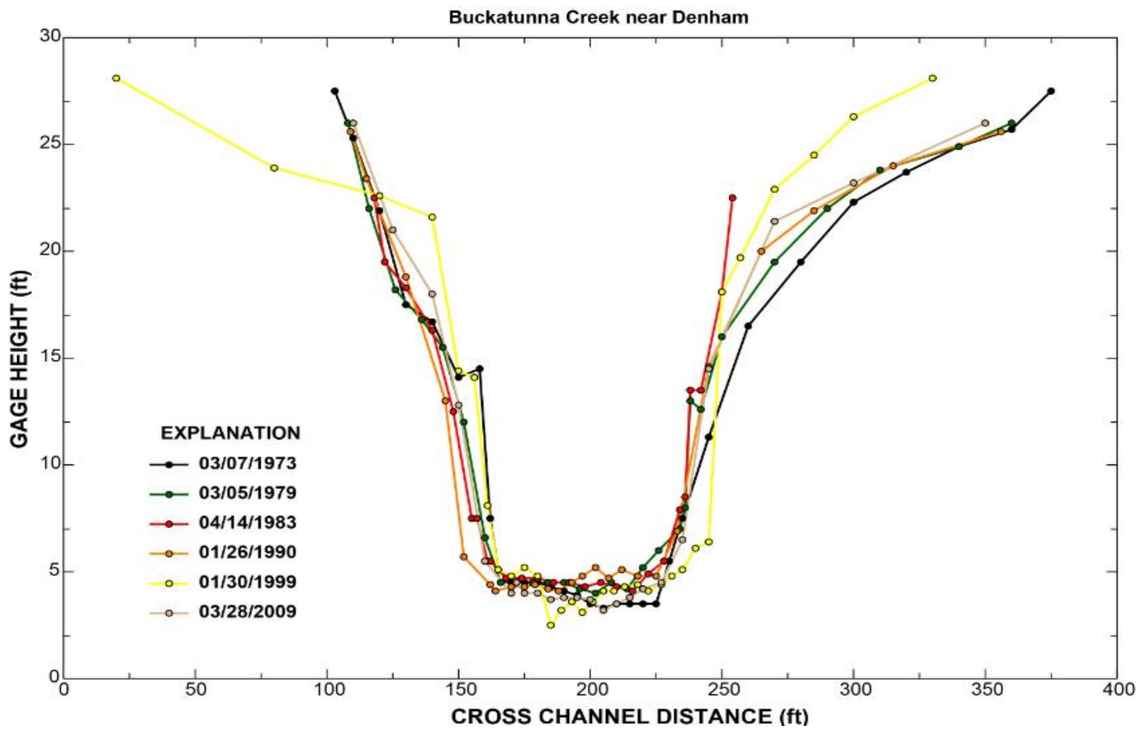


Figure 25. Cross-sectional profile summarizing historical channel adjustment for Buckatunna Creek near Denham (USGS 02477990). Cross-section view is downstream, x-axis is distance from the left-water-edge.

Table 11

Spatial and Hydraulic Values Calculated from WINXSPRO for Buckatunna Creek near Denham.

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1973	15	1293.73	143.82	0.0006	4.55	5885
1983	15	1326.69	126.24	0.0006	5.00	6630
1999	15	1177.25	104.05	0.0006	5.08	5980
2009	15	1274.20	119.41	0.0006	5.27	6714

Chickasawhay River at Leakesville (02478500)

Figure 26. Site location along the Chickasawhay River at Leakesville, MS. U.S. Geological Survey streamflow-gaging station 02478500 is marked with a grey indicator (ESRI 2014).

The channel area and width went largely unchanged over the study period (1940–1994). The long straight reach of the Chickasawhay approaching the gage yields a symmetrical channel profile. The minute changes in area recorded (Table 12) resulted from routine scour and fill during moderate and high-fill stages. In the high-flow measurements of 1990 and 1994 the bridge pier is prominently displayed. The relief of the sediment accumulated at the base of the pier is not as pronounced during the other moderate to low-flow measurements. This overall profile is comparable to the conceptual diagram presented in Figure 3 and to the similar obstruction influenced accretion at the Chickasawhay at Enterprise.

The stability in channel form for this reach is in accordance with Mossa and Coley (2004). Bank position appears to be stabilized by cohesive mudstones, while the bed is comprised of non-cohesive sands.

Construction of a new bridge upstream in 1995 rendered the traditional gaging station obsolete. Data collection after 1995 was done by boat.

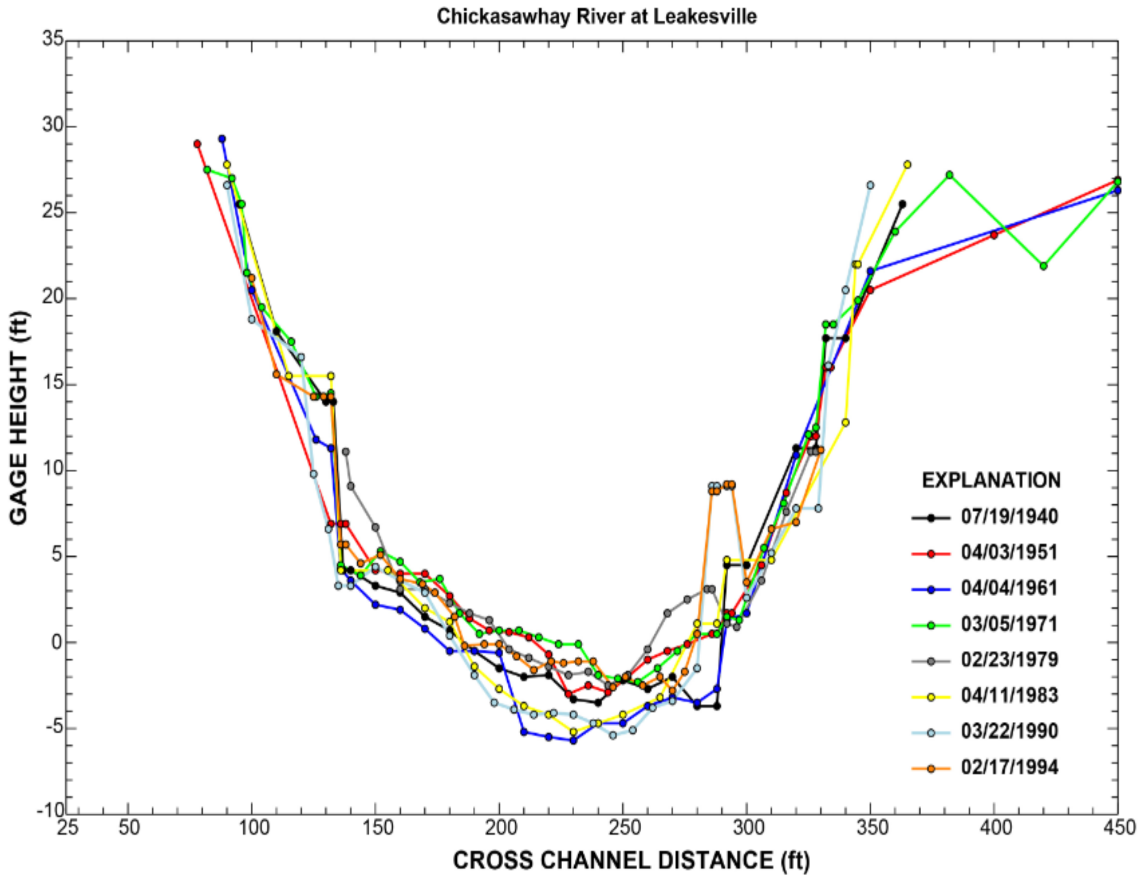


Figure 27. Cross-sectional profile summarizing historical channel adjustments for the Chickasawhay River at Leakesville (USGS 02478500). Cross-section view is downstream, x-axis is distance from the right-water-edge.

Table 12

Spatial and Hydraulic Values Calculated from WINXSPRO for the Chickasawhay River at Leakesville.

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1940	20	3010.21	212.34	0.0002	3.39	10203
1961	20	2866.54	211.00	0.0002	3.36	9618
1971	20	3084.83	216.67	0.0002	3.43	10595
1983	20	2831.90	208.62	0.0002	3.33	9424
1990	20	2844.51	210.81	0.0002	3.25	9243
1994	20	3016.33	222.86	0.0002	3.25	9799

Pascagoula River at Merrill (02479000)

Figure 28. Site location along the Pascagoula River at Merrill, MS. U.S. Geological Survey streamflow-gaging station 02479000 is marked by a grey indicator (ESRI 2014).

Gaging station is located at a relatively straight reach of the Pascagoula River immediately downstream of the confluence of the Chickasawhay and Leaf Rivers and exhibits a symmetrical form that appears entrenched. The right bank occasionally experiences change in position, probably from artificial reinforcement during the 1950s and subsequent removal of the material during the 1974 flood (139,000 ft^3/s). Changes in area directly connect to undulation of channel bed, as large bed forms are accreted and removed. The significant drop in bed elevation approximately 3–9 feet, measured in 1964, follows discharge events of 178,000 (ft^3/s) in 1961 and 90,000 (ft^3/s) in 1962. The increase in area calculated during the 1989 reading (27% greater than the profile in 1983) is directly related to consistent bed elevation and increase in width, approximately 20 feet.

The Pascagoula River as the main-stem channel for the basin appears to be governed by natural input cycles, more than any anthropogenic forcing. Mossa and Coley (2004) rated the Pascagoula as having high stability from a planform perspective, supported by the cross-sectional profile; measured instability is expressed in the channel bed form.

Data collection at this station after 1989 was performed by boat sounding.

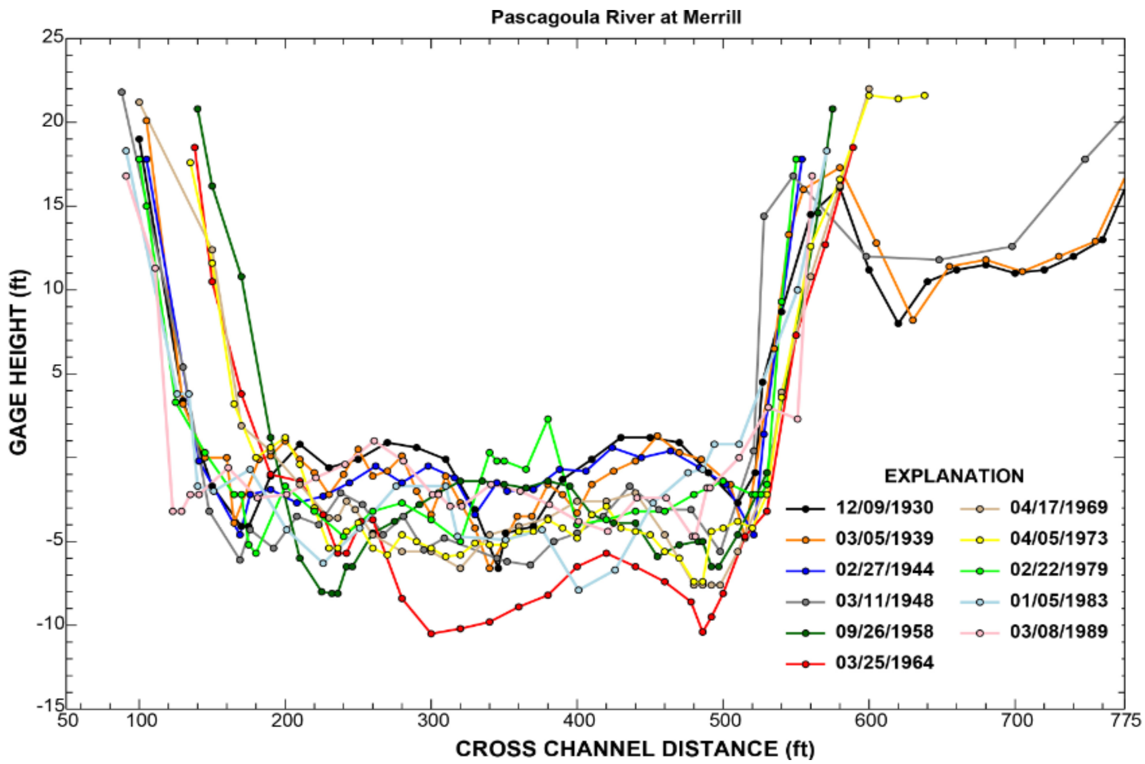


Figure 29. Cross-sectional profile sumamrizing historical channel adjustments for the Pascagoula River at Merrill (USGS 02479000). Cross-section view is downstream, x-axis is distance from right-water-edge.

Table 13

Spatial and Hydraulic Values Calculated from WINXSPRO for the Pascagoula River at Merrill.

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1939	15	3921.92	418.14	0.0003	3.76	14764
1948	15	4924.82	403.30	0.0003	4.24	20879
1958	15	3718.98	370.90	0.0003	3.74	13910
1969	15	4167.56	390.62	0.0003	3.90	16272
1979	15	4798.81	425.26	0.0003	4.02	19301
1983	15	4101.52	420.36	0.0003	3.68	15085
1989	15	5201.78	444.69	0.0003	4.11	21388

Black Creek near Brooklyn (02479130)

Figure 30. Site location along Black Creek near Brooklyn, MS. U.S. Geological Survey streamflow-gaging station 02479130 is marked with grey indicator (ESRI 2014).

Gage position is at a slight meander bend, resulting in asymmetrical channel form. The cross-section exhibits stable channel form for most of the study period, between 1973 and the mid 1990s, although this time frame is insufficient to accurately establish longer term adjustments. Both change in form and expansion in area during the latter stages of the study appear to be a response to artificial reinforcement of the right bank. After-reinforcement, thalweg flow was directed toward the left bank, resulting in approximately 25 feet of bank erosion and the development of a secondary channel. Adjacent to the reinforced side, lower bank accretion (bench formation) has occurred.

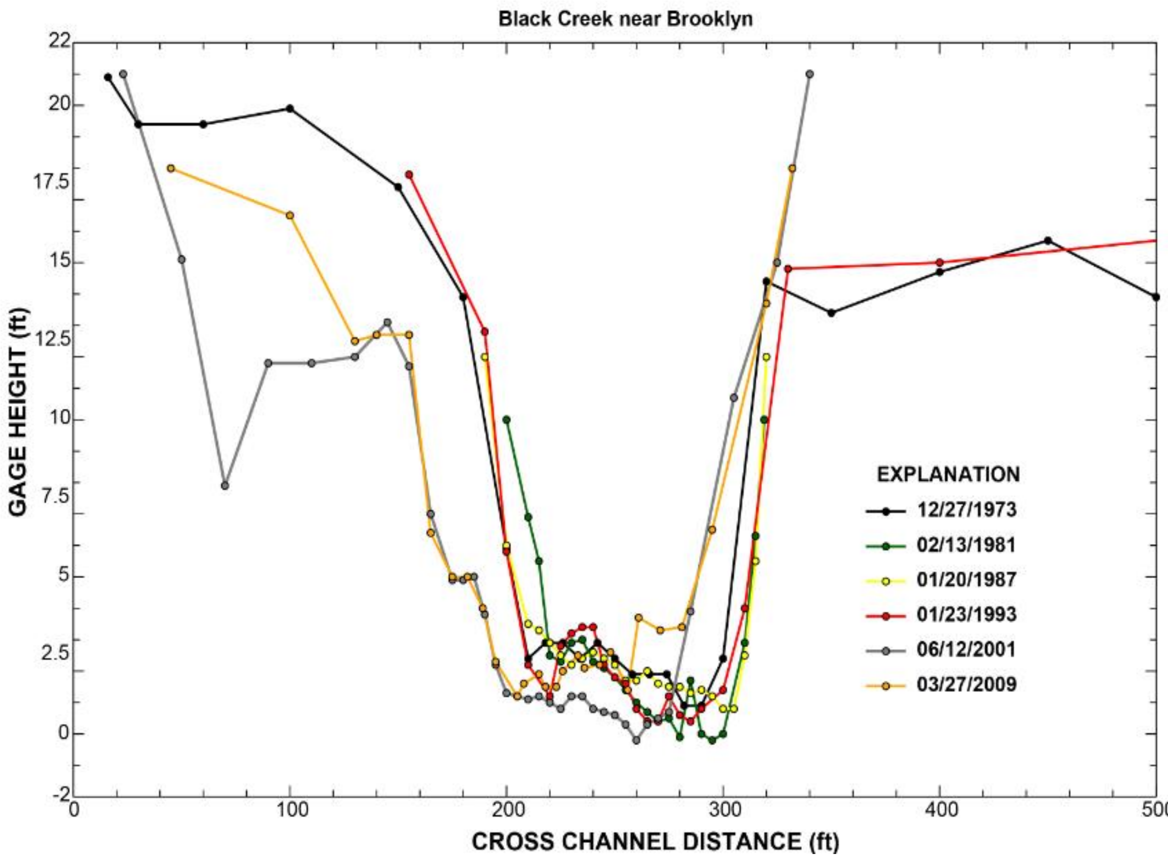


Figure 31. Cross-section profile summarizing historical channel adjustments for the Black Creek near Brooklyn (USGS 02479130). Cross-section view is downstream, x-axis is distance from the left-water-edge.

Table 14

Spatial and Hydraulic Values Calculated from WINXSPRO for Black Creek near Brooklyn.

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1973	12	1213.38	157.62	0.0006	4.16	5049
1993	12	1249.45	134.98	0.0006	4.67	5838
2001	12	1357.47	186.66	0.0006	4.03	5465
2009	12	1435.32	193.51	0.0006	4.09	5864

Cypress Creek near Janice (02479155)

Figure 32. Site location along Cypress Creek near Janice, MS. U.S. Geological Survey streamflow-gaging station 02479155 is marked with grey indicator (ESRI 2014).

Over the duration of this study, cross-sectional area for this reach of Cypress Creek decreased 29%. Channel width has also decreased almost 50% after 1992. Contraction occurs across each measurement but accelerates between 1992 and 2002. An abundance of sediment to the fluvial system is causing both bank and bed aggradation.

Cypress Creek is part of DeSoto National Forrest, a heavily wooded area. The gaging station is also downstream from Camp Shelby, a military training base. It has been shown that the use of tracked vehicles (e.g., tanks) on slopes greater than 10% can intensify erosion and introduce excess sediments into nearby streams (Patrick and Boyd, 2001). During the latter part of the study Camp Shelby saw a dramatic increase in the number of personnel and activity.

Although never a system of high discharge levels, 1979 and 1983 are the only instances within the study period that peak discharge was greater than 10,000 (ft^3/s); peak discharge dropped to just 962 (ft3/s) in 2000 and 719 (ft^3/s) in 2006.

It is important to note that in Patrick and Boyd (2001) it is stated clearly “the primary concern of land managers at Camp Shelby is the prevention of sedimentation in streams” (p.147).

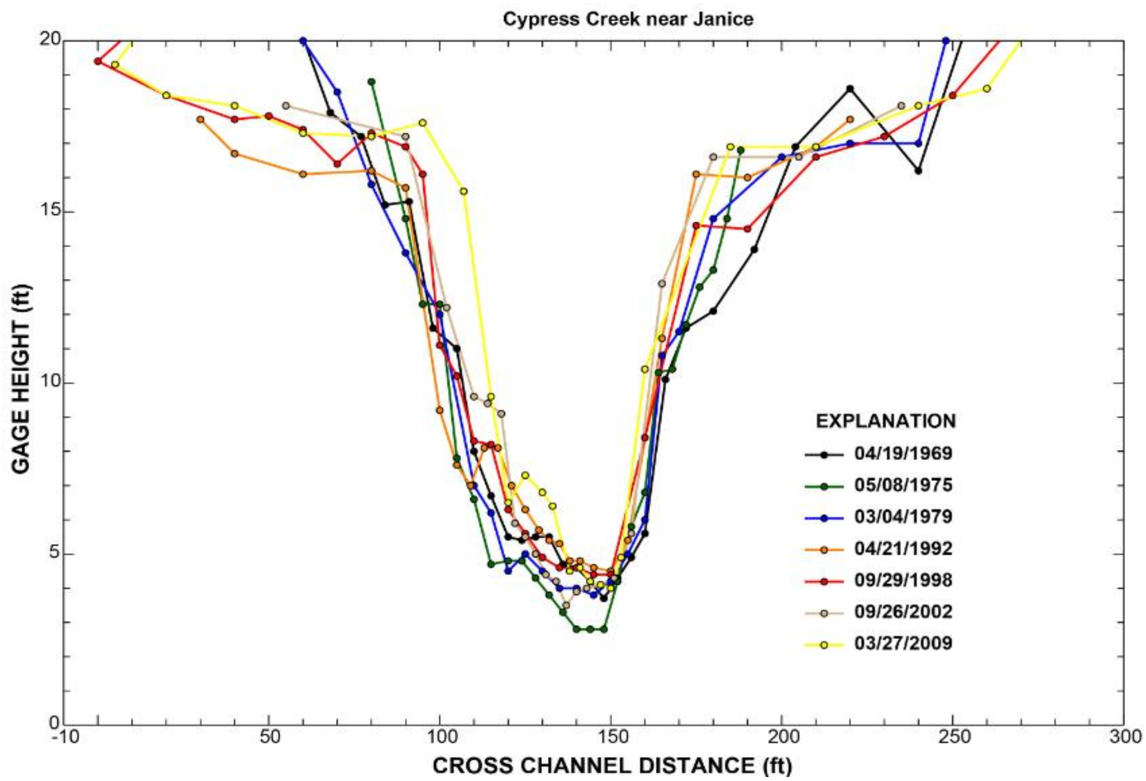


Figure 33. Cross-sectional profile summarizing historical channel adjustments for Cypress Creek near Janice (USGS 02479155). Cross-section view is downstream, x-axis is distance from the left-water-edge.

Table 15

Spatial and Hydraulic Values Calculated from WINXSPRO for Cypress Creek near Janice.

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1969	12	751.37	116.95	0.0004	3.31	2490
1979	12	745.80	111.11	0.0004	3.40	2538
1992	12	739.04	154.44	0.0004	2.81	2080
2002	12	575.72	81.46	0.0004	3.47	1995
2009	12	532.59	76.94	0.0004	3.39	1807

Black Creek near Wiggins (02479160)

Figure 34. Site location along Black Creek near Wiggins, MS. U.S. Geological Survey streamflow-gaging station 02479160 is marked with a grey indicator (ESRI 2014).

This section of the Black Creek near Wiggins, Mississippi is a well-entrenched reach between two meanders. The 1973 measurement marks the widest geometry and largest area for the study period. The greatest discharge events occur early in the study, in 1974 (25,000 ft^3/s) and 1979 (31,000 ft^3/s). A general scour-and-fill trend is visible throughout the study duration. The limited frequency and intensity of pulse events causes it to not be as pronounced as other gage locations (e.g., Chunky River). Fill is the more dominant component with resulting bed and bank aggradation. Years following the 1993 measurement recorded average peak discharges well below 10,000 (ft^3/s). The average for prior years, following the extreme discharge events of the 1970s, was 11,000 (ft^3/s). The large width and area calculation for the 2006 measurement is added by the flood plains inclusion in WinXSPRO for this measurement.

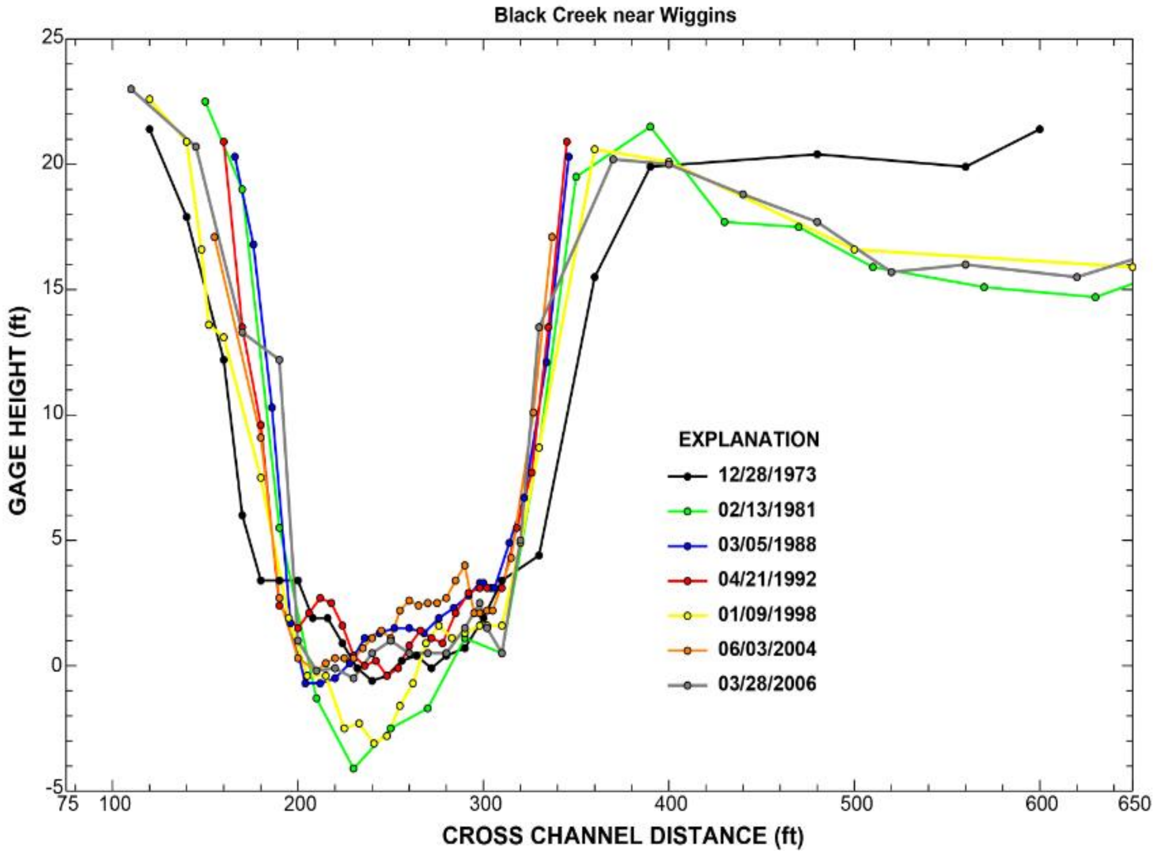


Figure 35. Cross-sectional profile summarizing historical channel adjustments for the Black Creek near Wiggins (USGS 02479160). Cross-section view is downstream, x-axis is distance from the left-water-edge.

Table 16

Spatial and Hydraulic Values Calculated from WINXSPRO for Black Creek near Wiggins.

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1973	18	2864.24	231.20	0.0004	5.29	15148
1981	18	2041.30	162.07	0.0004	5.28	10775
1998	18	2255.78	195.36	0.0004	5.03	11348
2006	18	2654.94	405.68	0.0004	3.45	9161

Red Creek at Vestry (02479300)

Figure 36. Site location along Red Creek at Vestry, MS. U.S. Geological Survey streamflow-gaging station 02479300 is marked by a grey indicator (ESRI 2014).

Construction of a new bridge along this reach in 1989 required profiles to be divided into periods A (1959–1988) and B (1998–2012). The two profiles appear similar, sharing common symmetry and width/depth relations. Period A is marked by scour and fill, accretion and denudation of large mid channel bed forms, and apparent channel migration resulting from right and left bank erosion. The new location for period B is a larger channel in terms of area, width, and depth. The channel area on average is 27% greater after bridge construction. Not only has size increased in period B, but the channel is also marked by stability in bed and bank position.

This section of Red Creek is documented with varying peak discharge events, almost alternating years of 5,000 (ft^3/s) to 20,000 (ft^3/s). These gages, and the stream as a whole, exist in a sparsely populated region. The trend exhibited by period A toward bed aggradation could be linked to increased vegetation. The location surrounding Red Creek is a forested area developed and maintained as state game land and fishing waterway. Further, in 2006 almost the entirety of Red Creek was established as a protected Mississippi watershed (MDWFP, 2014).

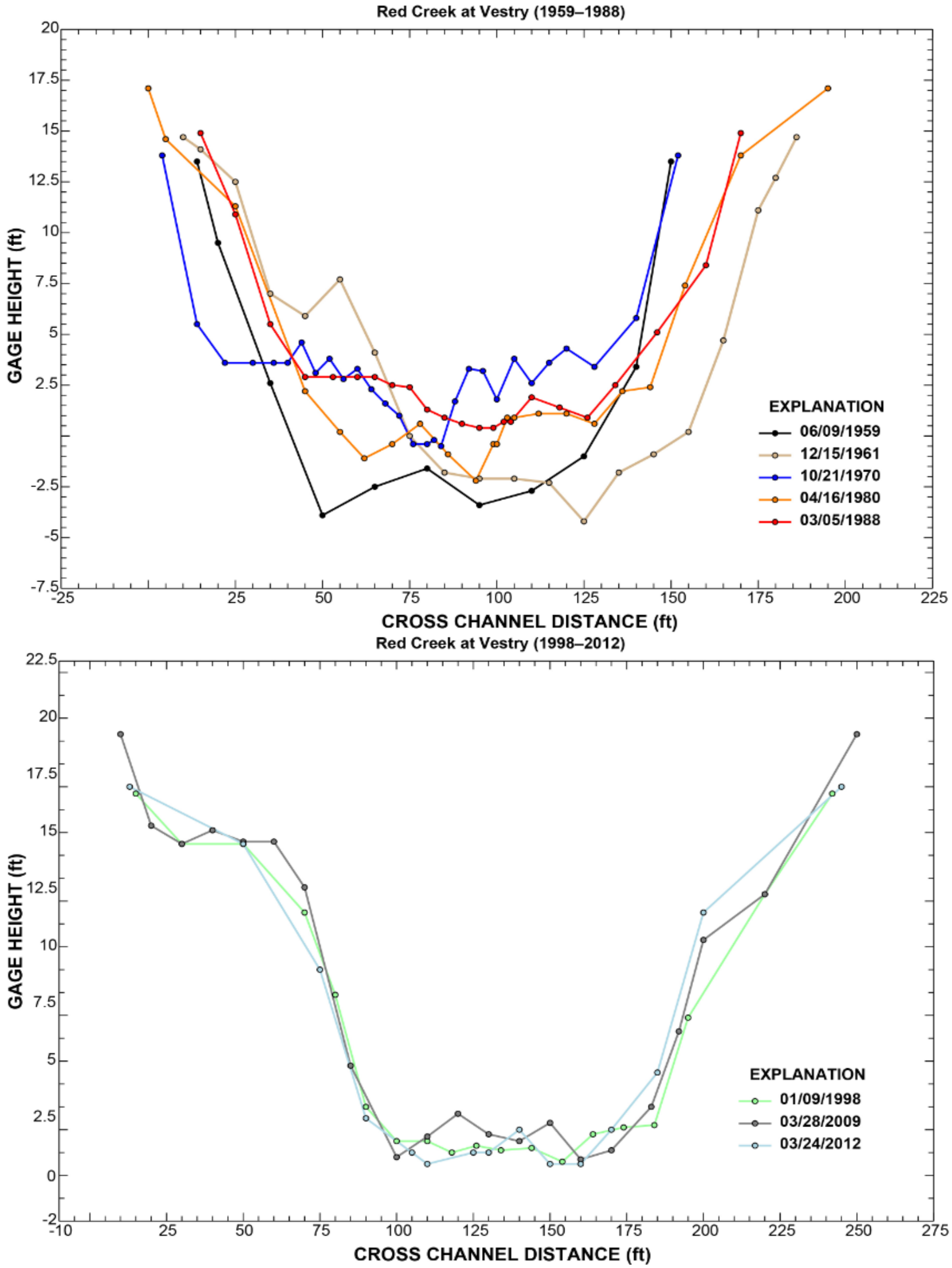


Figure 37. Cross-sectional profiles summarizing historical channel adjustments for the Red Creek at Vestry (USGS 02479300). (A) Gage location from 1959–1988. (B) Gage location from 1998–2012. Cross-section view is downstream, x-axis is distance from left-water-edge.

Table 17

Spatial and Hydraulic Values Calculated from WINXSPRO for Red Creek at Vestry.

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1961	15	1360.70	146.44	0.0002	2.62	3559
1980	15	1485.67	152.45	0.0002	2.71	4023
1998	15	1864.00	214.00	0.0002	2.54	4738
2009	15	1787.57	215.57	0.0002	2.45	4384

Biloxi River at Wortham (02481000)

Figure 38. Site location along the Biloxi River at Wortham, MS. U.S. Geological Survey streamflow-gaging 02481000 is marked with a grey indicator (ESRI 2014).

Gage placement is at a modest bend in the river; causing a slightly asymmetrical channel form characterized by a steep right bank. Following 1964 the channel exhibits a cycle toward decreasing cross-sectional area through bank and floodplain accretion, as well as bed aggradation. A large discharge event in 1983 (10,300 ft^3/s) temporarily reversed this trend by incising the bed approximately 4 feet. The 1993 profile provided the lowest area during the study period. Large discharge events in 1995 (13,500 ft^3/s) and 1998 (9,280 ft^3/s) once again impeded aggradation, but not as dramatically. Considering the expansion of section depth 1–5, 1998 is on average 225% larger than 1993. This section constituting the channel bed represents almost the entire change in area between the 1993 and 1998 measurements. Increased area in 2012 is a result of the erosion of the upper half of left and right banks. Cross-sectional morphologic adjustments during the study period appear to be a result of increased sediment yield.

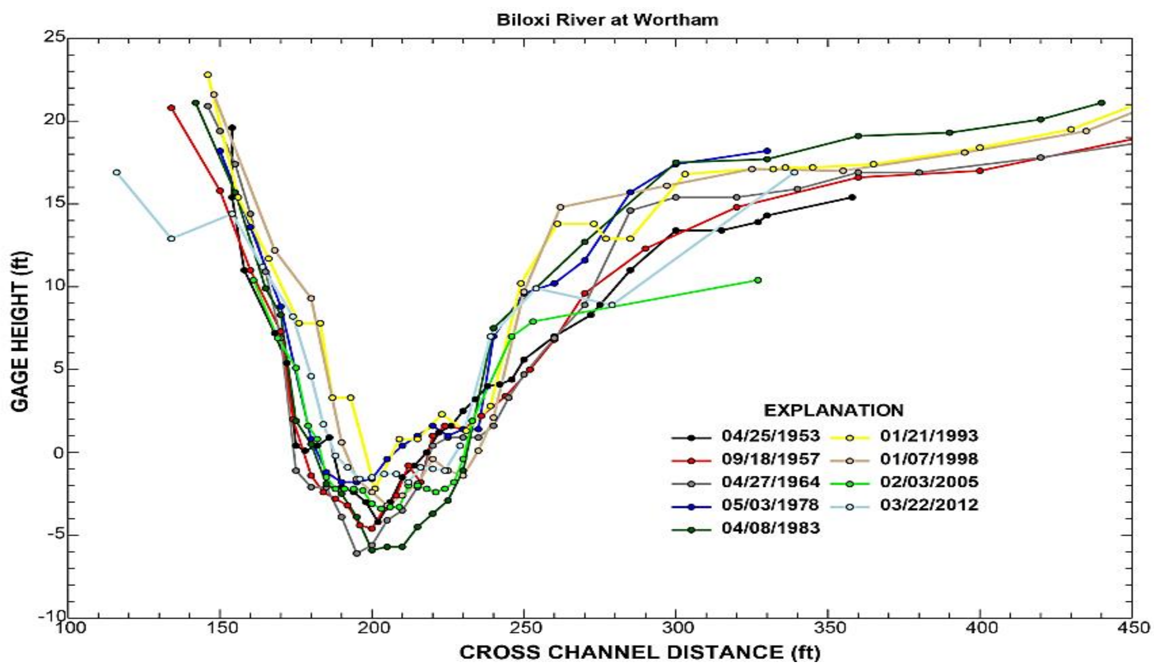


Figure 39. Cross-sectional profile summarizing historical channel adjustment for the Biloxi River at Wortham (USGS 02481000). The X-axis is increasing in distance from the right water's edge. Cross-section view is downstream.

Table 18

Spatial and Hydraulic Values Calculated from WinXSPRO for Biloxi River at Wortham.

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft3/s)
1957	15	929.56	114.30	0.0006	4.20	3905
1964	15	839.50	102.50	0.0006	4.18	3507
1978	15	986.35	115.02	0.0006	4.34	4279
1983	15	766.88	81.73	0.0006	4.32	3309
1993	15	769.40	94.64	0.0006	4.13	3179
1998	15	801.37	85.29	0.0006	4.53	3632
2012	15	1090.19	158.85	0.0006	-	-

Wolf River near Landon (02481510)

Figure 40. Site location along the Wolf River near Landon, MS. U.S. Geological Survey streamflow-gaging station 02481510 is marked with grey indicator (ESRI 2014).

Early cross-sectional form (1972—1977) of this reach of the Wolf River depicts a shallower, broader channel. Despite a vertical datum shift of 5 feet in 1979, the channel underwent deep incision, 6 to7 feet, during the 1980–1985 measurements. Subsequent channel bed aggradation, 3 to 4 feet, follows from the 1990s through 2005, with a small hingepoint developing in 2005. Incision is shown once more in the period between 2005 and 2012. Unlike the previous period of incision, elevation lowering is limited to thalweg portion of the channel bed. The lower half of the right bank greatly steepened, taking on a reinforced appearance. However, the consistently steep form of the left bank and general topography of the area would suggest this development is a natural occurrence and not anthropogenic reinforcement. A 24% decrease in area over the duration of the study is a reflection of the change in form and accretion from the right bank.

Incision may be a cyclical phenomenon of the channel location, but the 2012 measurement was driven by temporary scour occurring at a discharge greater than 20,000

(ft^3/s). Scour would have continued the next day, as August 31st had a discharge event greater than 30,000 (ft^3/s).

Located in Harrison County, Mississippi, gaging station 02481510 is adjacent (within 10 miles) to the Gulf of Mexico. A hypothesis for the Wolf River's entrenchment at this location is a combination of general topography and potential floods brought on by land falling tropical cyclones.

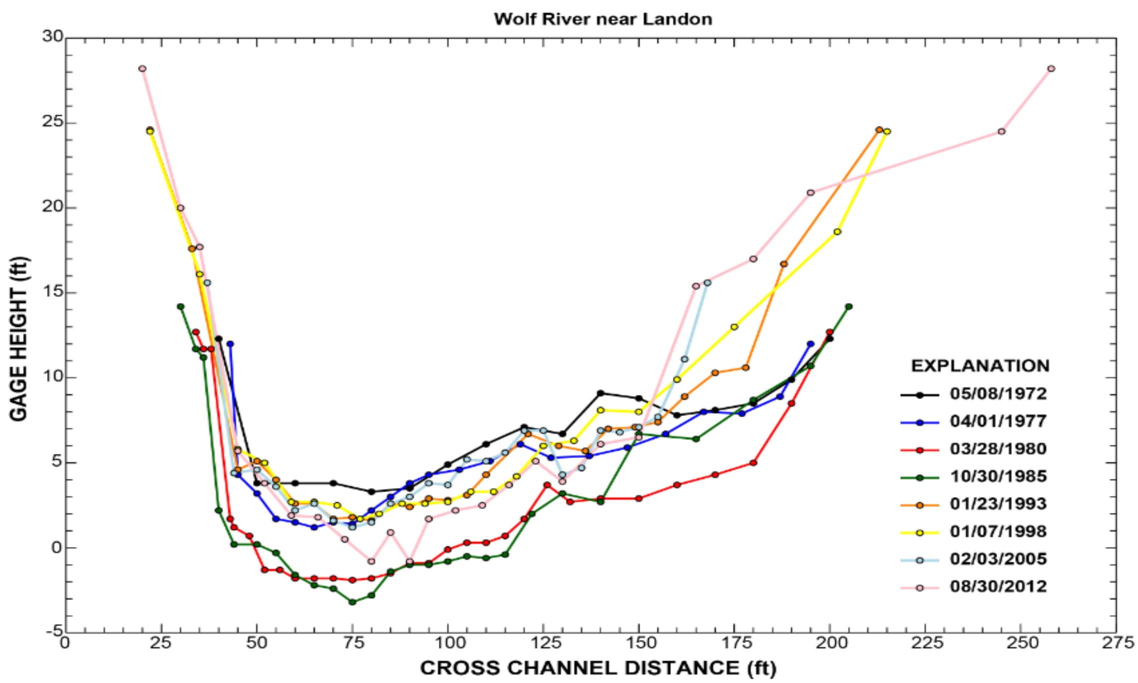


Figure 41. Cross-sectional profile summarizing historical channel adjustments for the Wolf River near Landon (USGS 02481510). Cross-section view is downstream, x-axis is distance from left-water-edge.

Table 19

Spatial and Hydraulic Values Calculated from WINXSPRO for the Wolf River near Landon.

Year	Stage (ft)	Area (sq ft)	Width (ft)	Slope (ft/ft)	Velocity avg. (ft/s)	Discharge Q (ft^3/s)
1977	15	1668.70	152.00	0.0003	3.98	6637
1985	15	1475.44	164.30	0.0003	3.59	5297
1998	15	1560.73	158.77	0.0003	3.84	5999
2012	15	1268.07	125.06	0.0003	4.04	5635

CHAPTER V

CONCLUSIONS

The study area was hypothesized, due to its geological setting and status as the largest unregulated basin in the contiguous 48 states, to most accurately depict cross-sectional historic channel adjustments from natural factors (e.g., natural sediment vs. hydrologic flux). However, despite proving useful for interpreting change at each location, channel cross sections generated from USGS gaging station reports were not able to be extrapolated to characterize the entire channel reach or basin. Assertions in this thesis are only interpretations based on a limited understanding of watershed dynamics. Therefore, it is impossible to definitively associate channel adjustments with anthropogenic disturbances without other data to corroborate these findings.

Most of the rivers in this study were represented by one gaging station; however, even those with multiple stations could not draw direct comparisons across the long distance. A succession of profiles at close distances like those in Sarmah (2012) will depict a more accurate profile of the entire channel reach. Gaging stations at bridges provide an easy access point to collect long-term and extensive data. However, artificial hydraulics from bridge features can make it difficult to extrapolate information from cross-sections if that potential is not taken into account (Heitmuller, 2014). This study consulted the National Bridge Inventory Database (Nationalbridges.com, 2013) to account for such activities. A combination of the cross-sections created from USGS hardcopy notes used with historical site photographs or in situ observations, as seen in previous studies (e.g., Sarmah, 2012; Ziliani and Surian, 2012; Heitmuller, 2014), would have aided in further differentiating the two causes. For the conclusion of this paper, channel forms in dispute were assumed to have been anthropogenic in nature and were counted in that percentage (e.g., Chickasawhay at Enterprise, Cypress Creek).

Of the 19 gaging stations analyzed, seven (37%) had no discernable impact from anthropogenic causes. Eight stations (42%) had cross sections that were either divided between bridge locations but still represented natural form (e.g., Red Creek, Bouie Creek), or channel form was affected by bridge features only a fraction of the study period (e.g., Chickasawhay at Leakesville, Black Creek near Brooklyn). Only four stations (21%) experienced significant and lengthy channel form directed by anthropogenic influence (e.g., Cypress Creek, Chickasawhay near Enterprise). The selection of the Pascagoula River basin based on the aforementioned assumption appears correct. Of the 19 gaging stations, 15 (79%) demonstrated the cross-sectional geometric response of the channel to historical environmental conditions.

My conclusion, that channel forms in rivers comprising the Pascagoula basin are authored by natural influences, was supported by the results and the response from MDEQ to my FOIA request. The MDEQ official assured me that channelization activities, especially in stream or floodplain mining, were strictly prohibited. The only exception would be in older profiles of the Bowie and Leaf Rivers. This information was verified by the cross-sectional profiles.

An aspect of having channels that are open to the influence of natural systems is that it is difficult to discern trends toward specific mechanisms or styles of change. At last measurement the majority of channels appeared to be in a stable form; however, by this moment new cycles of incision or aggradation may have already started. Additionally, the periods of record of this investigation post-dated the peak of the logging industry (1880s–1920s) in southeastern Mississippi. Therefore, the earliest cross-sections, the initial form from which that adjustment is discerned, might represent phases of channel recovery following likely episodes of hillslope erosion, log jams, and other logging-related activities.

APPENDIX A

FOIA LETTER

Mr. Boddie,

My name is Michael Ayers and I am currently a graduate student at the University of Southern Mississippi; writing my thesis for the completion of a Master's degree. Said thesis is a study of channel change in streams of the Pascagoula River Basin over the last few decades, using flow records from the USGS.

In order to better understand and explain the observed changes to channel form witnessed during the study I would like to some information about economic activities (e.g. in-stream gravel mining) that have occurred along the rivers in my study. I would not need access to any particulars such as the names of the companies involved. I understand the desire for anonymity from such companies. I only ask for the timeframes that any extraction or construction was occurring and an approximate area of the river reach. The period of study spans from the 1940's through the early 2000's and involved the following rivers:

- Black Creek
- Leaf River
- Bouge Homo
- Tallahala Creek
- Biloxi River
- Chickasawhay River
- Chunky Creek

Thank you for considering my request. Any information that can be provided on the rivers above will greatly help me in defense of my thesis.

Michael Ayers

APPENDIX B

WINXSPRO EXAMPLE DATA SET

```
********************************WinXSPRO*********************************
E:\thesis\02479000_WINXSPRO\79222.out
Input File:              E:\thesis\02479000_WINXSPRO\79222.txt
Run Date:                02/25/14
Analysis Procedure:      Hydraulics
Cross Section Number:    1
Survey Date:             02/25/14


Subsections/Dividing positions


Resistance Method:        Manning's n
           SECTION          A
      Low Stage n         0.045
      High Stage n        0.030

Unadjusted horizontal distances used
```

STAGE (ft)	#SEC	AREA (sq ft)	PERIM (ft)	WIDTH (ft)	R (ft)	DHYD (ft)	SLOPE (ft/ft)	n	VAVG (ft/s)	Q (cfs)	SHEAR (psf)
1.00	T	7.32	16.89	16.58	0.43	0.44	0.0003	0.044	0.33	2.45	0.01
2.00	T	53.29	91.00	90.02	0.59	0.59	0.0003	0.043	0.42	22.27	0.01
3.00	T	204.29	215.38	213.64	0.95	0.96	0.0003	0.042	0.59	120.17	0.02
4.00	T	452.27	295.49	293.09	1.53	1.54	0.0003	0.041	0.83	373.81	0.03
5.00	T	766.59	327.69	324.53	2.34	2.36	0.0003	0.041	1.12	858.97	0.04
6.00	T	1116.55	374.47	370.39	2.98	3.01	0.0003	0.040	1.35	1503.41	0.06
7.00	T	1494.82	391.00	386.15	3.82	3.87	0.0003	0.039	1.63	2429.51	0.07
8.00	T	1888.86	407.52	401.91	4.63	4.70	0.0003	0.038	1.89	3571.62	0.09
9.00	T	2294.56	415.62	409.50	5.52	5.60	0.0003	0.037	2.18	4991.39	0.10
10.00	T	2705.37	418.96	412.12	6.46	6.56	0.0003	0.036	2.47	6692.42	0.12
11.00	T	3118.80	422.30	414.75	7.39	7.52	0.0003	0.035	2.77	8648.60	0.14
12.00	T	3534.87	425.64	417.38	8.30	8.47	0.0003	0.034	3.08	10871.85	0.16
13.00	T	3953.56	428.97	420.00	9.22	9.41	0.0003	0.034	3.38	13376.66	0.17
14.00	T	4374.87	432.31	422.63	10.12	10.35	0.0003	0.033	3.70	16180.11	0.19
15.00	T	4798.81	435.65	425.26	11.02	11.28	0.0003	0.032	4.02	19301.97	0.21
16.00	T	5225.51	439.17	428.14	11.90	12.21	0.0003	0.031	4.36	22759.44	0.22
17.00	T	5655.10	442.70	431.03	12.77	13.12	0.0003	0.030	4.70	26584.09	0.24

STAGE	ALPHA	FROUDE
1.00	1.000000	0.088847
2.00	1.000000	0.095701
3.00	1.000000	0.106010
4.00	1.000000	0.117252
5.00	1.000000	0.128479
6.00	1.000000	0.136667
7.00	1.000000	0.145574
8.00	1.000000	0.153711
9.00	1.000000	0.161945
10.00	1.000000	0.170149

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